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THE ILLUMINATION AND BEACONING OF AERODROMES

by G. L. van HEEL. 628.971.8 : 656.71

After a discussion of the visibility of different sources of coloured light and their use as beacons on aerodromes, the illumination of obstacles, of the boundaries of the aerodrome and of the landing area is dealt with. Finally the special precautions are discussed which should be taken in the case of landing in mist: approach lights, access lights and illuminated buttons in the landing area.

Introduction

Although the illumination of aerodromes is still at the beginning of its development, many problems which are connected with good beaconing and illumination of aerodromes can already be solved satisfactorily by the use of modern gas discharge lamps. Since, when different sources of coloured light are used for marking an aerodrome, the question arises as to the degree to which the colours used may be confused with each other or with other colours in clear weather as well as in more or less thick mist, we shall begin with a short discussion of the visibility of different sources of coloured light under different weather conditions, and the possibilities for their use arising therefrom. We shall then deal in turn with possibilities of satisfying the requirement that the pilot, in order to make a safe and smooth landing, must be able to orient himself as to the place, height and position of his machine. With good visibility it is desirable and possible to make the following features plainly visible to him:

a) the shape and the boundaries of the part of the field suitable for landing (boundary lights);
b) the obstacles in the immediate neighbourhood of the aerodrome (obstruction lights);
c) the wind direction;
d) the surface of the part of the field on which he must land, in order to be able to carry out the actual landing (illumination of the landing area).

We shall finally discuss the measures for landing with poor visibility.

Visibility and the use of sources of different coloured light

In choosing the different colours to be used in the illumination of an aerodrome care must be taken to make it impossible to confuse the different colours, while they must also not appear too much changed in character in misty weather for the observer at some distance.

The colours proposed by the I.C.I. (International Commission on Illumination) in 1935 and later prescribed by the C.A.I. (Conférence Aéronautique Internationale) for aerodrome lighting are determined [1]) as follows in the colour triangle (*fig. 1*). For red a colour may be used out of an extended region lying along the spectral red with a dominant wave length of at least 6 100 Å, which corresponds to a limitation in height by the condition that $y \leqslant 0.35$. The width is restricted by the condition that $z \leqslant 0.002$, by which a saturation of at least 97 per cent is ensured. Neon light has the coordinates $y = 0.325$ and $z = 0.003$ in the colour triangle and thus satisfies the requirements for aeronautical red. As aeronautical yellow a broader rectangle in the colour triangle has been determined which is bounded by the following conditions: $z \leqslant 0.007$ and $0.402 \leqslant y \leqslant 0.46$, so that the wave length lies between 5 840 and 5 940 Å while the saturation is at least 97 per cent. Yellow sodium light has the coordinates $y = 0.428$ and $z = 0.007$ and therefore falls in the middle of this rectangle. For "aeronautical green" a large region is allowed in the right-hand upper corner of the colour triangle which is limited at the lower side by the lines:

$$z = 0.610 - 0.829\ y$$
$$z = 1.170 - 2\ y$$
$$0.24\ z = 0.76\ y - 0.173.$$

[1]) *Cf.*: Philips techn. Rev. 2, 39, 1937.

The experience which has been obtained since 1935 in the actual practice of aerodrome illumination with the colours thus determined, gives as yet no occasion for changing the colours. It is clear that the limits of these colours in the colour triangle are so far away from each other that sources of light emitting these three colours cannot be confused with each other in clear weather. It might, however, still be asked whether in the case of haze or thick mist and when observed from a greater distance the colour might not be so much changed that it could be mistaken. The variation of colour in haze and mist can be caused by selective absorption, or because the intensity becomes so low that colourless vision with the rods of the eye (Purkinje effect) begins to play a part. In that case red remains the easiest colour to recognize, while blue and green quickly become indistinguishable. It is a great advantage of sodium lamps that they emit a practically monochromatic yellow light which retains its colour well even at low intensity while a change of colour due to selective absorption is impossible.

Although experience (in the illumination of roads) has shown that sodium light penetrates haze very well, with a thick mist there is no great difference between the penetrating power of lights of different colours. Sodium lamps, however, have an advantage in that case also over ordinary electric lamps, namely the high luminous intensity which is obtained already with small current consumption.

Especially for the lights to be used for marking the aerodrome and its surroundings colours should be used which are as striking as possible. In this respect red occupies the first place, so that it is obvious that this colour should always be used to indicate danger. In agreement with common practice point sources of red light are prescribed by the C.A.I. to indicate obstructions. By the prescription of the shape of the source the possibility of using linear sources of red light for the boundary lights of an aerodrome is left open, since this was already customary in Germany. For boundary lights yellow is now internationally prescribed, with the understanding that linear red lights and under special circumstances white flicker lights may also be used. In agreement with the custom also prevailing in signal services green is recommended to indicate places where certain manouvres can be carried out safely. With this colour therefore may be indicated, for example, where it is best to approach the aerodrome.

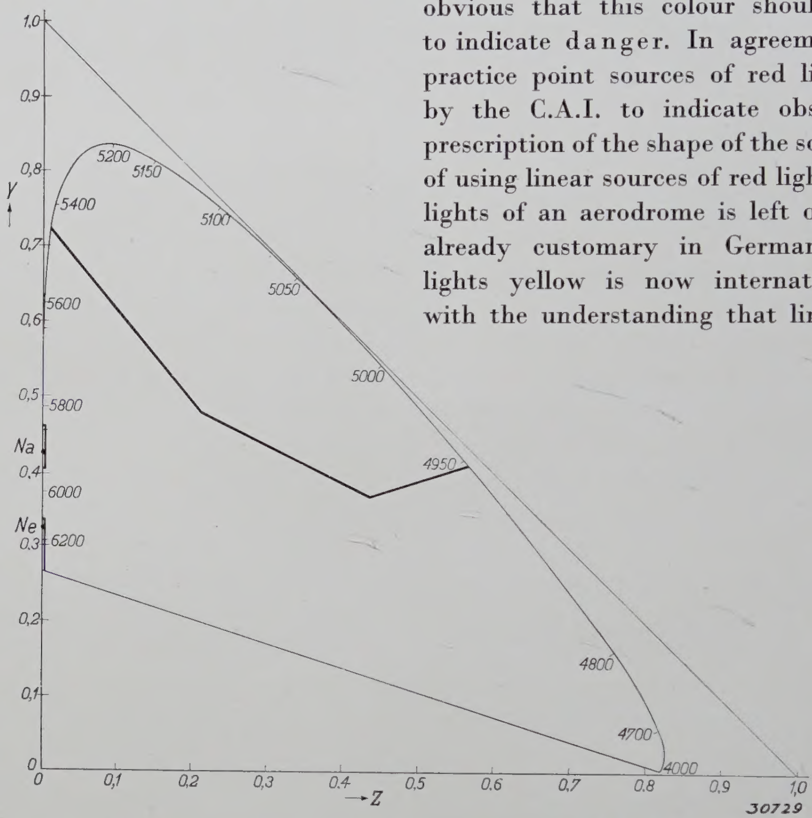

Fig. 1. Colour triangle according to the system recommended by the I.C.I. in 1931 (*cf.* Philips techn. Rev. **2**, 45, 1937: fig. 4, in which y and z are indicated by t_2 and t_3 respectively). The spectral colours lie on the full line curve; their wave lengths are indicated. The regions sketched represent the colour regions prescribed for aeronautical lights for red, yellow and green. Ne and Na indicate respectively the colour point of red neon and yellow sodium light.

Boundary lights

The main function of boundary lights consists in the fact that they must indicate the safe boundaries of the aerodrome to the pilot in an easily recognizable way. It is therefore essential that it be impossible ever to confuse the boundary lights

with other sources of light either on or near the aerodrome. It is best therefore not to use white boundary lights. For districts where electric current is not easily available, and where, therefore, use must be made of acetylene flickers for example, white boundary lights must obviously be used, although in this case precautions must be taken against glare.

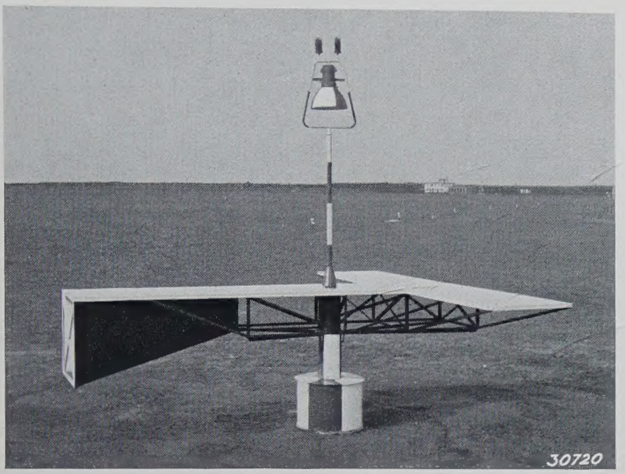

Fig. 2. Illuminated wind indicator.

The boundary lighting generally used in Germany with linear red neon lamps does not of course guarantee the impossibility of confusion with red point sources as obstruction lights in the case of heavy mist as absolutely as does yellow boundary lighting. If yellow boundary lights are to be installed, the use of simple sodium lamps, for instance "Philora" type SO 250, offers many advantages for this purpose over the use of sources of white light provided with a yellow filter. With equal current consumption 10 times as much light is obtained as with ordinary lights with a yellow filter, and as to colour one is not dependent upon the accuracy with which the filters are manufactured.

The colour of the monochromatic light of sodium lamps cannot change in misty weather due to selective absorption, as we have already seen. Moreover yellow sodium light has the advantage over white light that, due partly to the low brightness of the sources, it gives only little occasion for glare.

The boundary lights must if possible also serve as an aid in estimating the height of the machine and the dimensions of the field. In other words they must by perspective give the pilot an idea of his position above the field and also make it possible for him to see at a glance the size of the field by counting the lights. Therefore it has been prescribed internationally that the boundary lights should be placed along the boundary of the aerodrome at equal distances of 100 m.

Obstruction lights

It is not difficult to provide that all obstructions around the landing area are indicated by point sources of red light, so that they are immediately recognized as obstructions by the pilot. The objects which must be considered as obstructions are determined by their height in realation to the shortest distance to the edge of the landing area. It is further to be recommended generally that buildings in the immediate neighbourhood of the aerodrome be made visible by a simple system of floodlighting. This gives the scene more depth and it makes it easier for the pilot to judge his height.

Indication of the direction of the wind

For making a landing under normal circumstances it is very important for the pilot to know the exact direction of the wind at the surface of the field. This direction is indicated by a T-shaped wind indicator, and it is therefore essential that this should be well lighted. In the simple construction shown in *fig. 2* the white upper surface of the T can be brightly lighted by means of a mercury lamp. Against the dark background the bright T gives a good contrast which is enhanced by the T-shaped shadow cast by the wind indicator on the ground (*fig. 3*).

Illumination of the landing area

The super high pressure mercury discharge has several properties which make it particularly

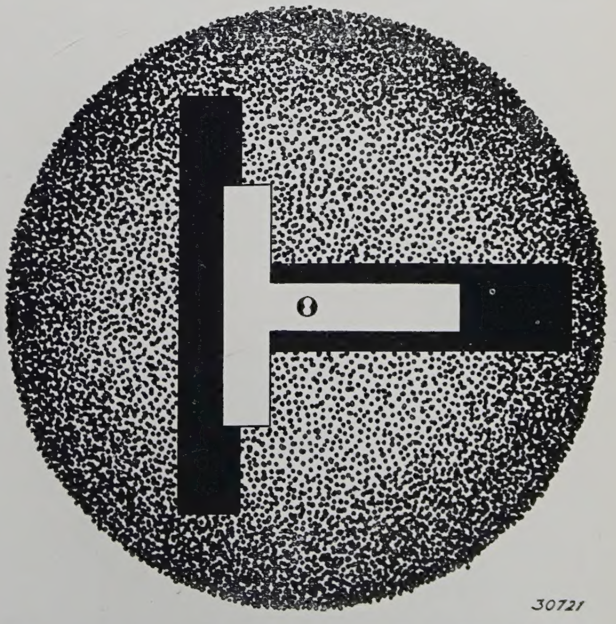

Fig. 3. The illuminated white upper surface of the T contrasts especially strongly with its own shadow.

suitable for use in floodlighting the landing area. In the first place the discharge column is long and slender so that such a lamp is very suitable for mounting along the focal line of a parabolic cylindrical reflector in order to obtain a fan-shaped beam which has wide horizontal and slight vertical spread. Furthermore these lamps have high brilliance and efficiency, while the spectral composition of the light which they emit is very favourable as we shall see later.

The landing area light constructed by Philips which is already installed on several Netherlands aerodromes consists of two mercury lamps of 1 000 W whose 25 cm discharge columns are mounted in two parabolic cylindrical mirrors one above the other. As may be seen from the horizontal light distribution curve (*fig. 4*) the horizontal spread of the beam is about 120°, so that a large area of the field is covered by such a landing area light. Because of the small diameter of the discharge it was possible to limit the vertical spread to a few degrees, as may clearly be seen in the vertical light distribution curves of *fig.* 5. The light flux is 40 000 lumens per mercury lamp, while the maximum brightness is 1 400 c.p./sq.cm. If the losses at the covering glass of the reflector are taken into account the maximum luminous intensity per mirror is 250 000 c.p. By adjusting the mirrors in the correct way it is therefore possible to obtain a total intensity of 500 000 c.p. as indicated in figs. 4 and 5.

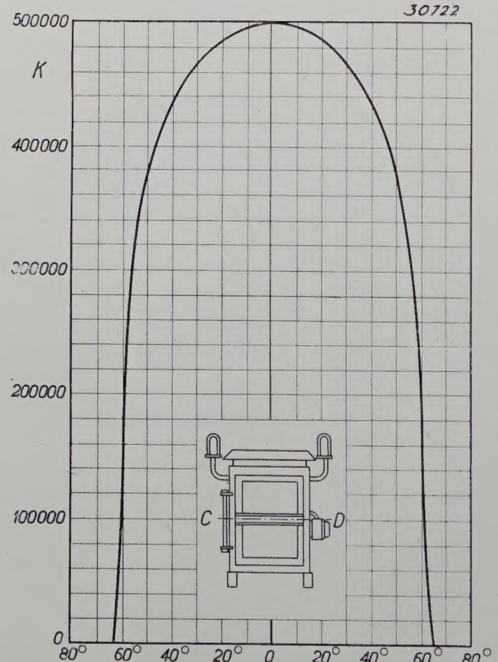

Fig. 4. Curve for horizontal light distribution (in candle power) of a landing area floodlight with about 120° horizontal spread of the beam.

Such a landing area light may be placed upon a simple steel construction at a height of a few metres at the edge of the aerodrome as shown

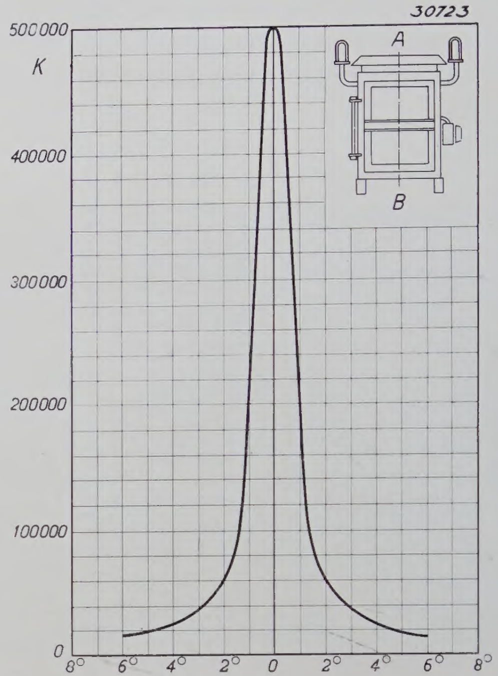

Fig. 5. Curve for vertical light distribution (in candle powers) of a landing area floodlight with only about 2° vertical spread of beam.

in *fig. 6*. When after landing the machine taxis across the field toward the station building or hangar, the pilot might be blinded by the oblique beam of the landing light, and it should then be extinguished. If these mercury lamps of 1 000 W are switched off and then immediately afterwards on again, it is several minutes before they have cooled off enough to re-ignite, and it then takes several minutes more before they have reached full intensity. It will be obvious that because of this, lamps of this type are particularly suitable for small aerodromes at which only a few airline machines land, and whose time of arrival is known precisely by means of the radio. Because of the much heavier traffic larger aerodromes usually require that the landing lights must be able to be switched on and off quickly. For this purpose it is possible to provide the landing lights with shutters which can be operated at some distance so that it becomes unnecessary to switch the lamps themselves on and off. It is then moreover possible, at the request of the pilot about to land, immediately to add to or substract from the number of lights.

The result obtained with the landing lights is usually judged by measuring the intensity of illumination at different spots throughout the whole field on areas 10 cm above the ground perpendicular

to the incident rays. In *fig.* 7 curves are drawn on the field connecting points with equal intensity of illumination under illumination by one mercury lamp of 1 000 W (iso-lux curves). From these curves it may be seen that with a landing light which contains two of these mercury lamps one does not obtain at least 2 lux over an area of 600 by 300 m, as is proposed in the international recommendations. Nevertheless this landing light is found to be satisfactory in practice, which fact is due to the spectral composition of the mercury light. Mercury light is unusually suitable for the illumination of a green grass field! The light of the mercury lamps consists namely

for 33% of the yellow line from 5 770 - 5 790 Å,
for 53% of the green line at 5 460 Å,
for 1% of the blue and violet lines at 4 358 Å and from 4 047 - 4 078 Å, and
for 13% of the continuous background of the spectrum.

Because of its high content of green, mercury light is particularly suitable for illiminating a green field. As has already been discussed elsewhere in this periodical [2]) the sharpness of vision is also much greater for mercury light than for other technically used lights. It is therefore possible to observe the small irregularities of the field better with mercury light, so that during landing the height above the ground can be estimated with more confidence.

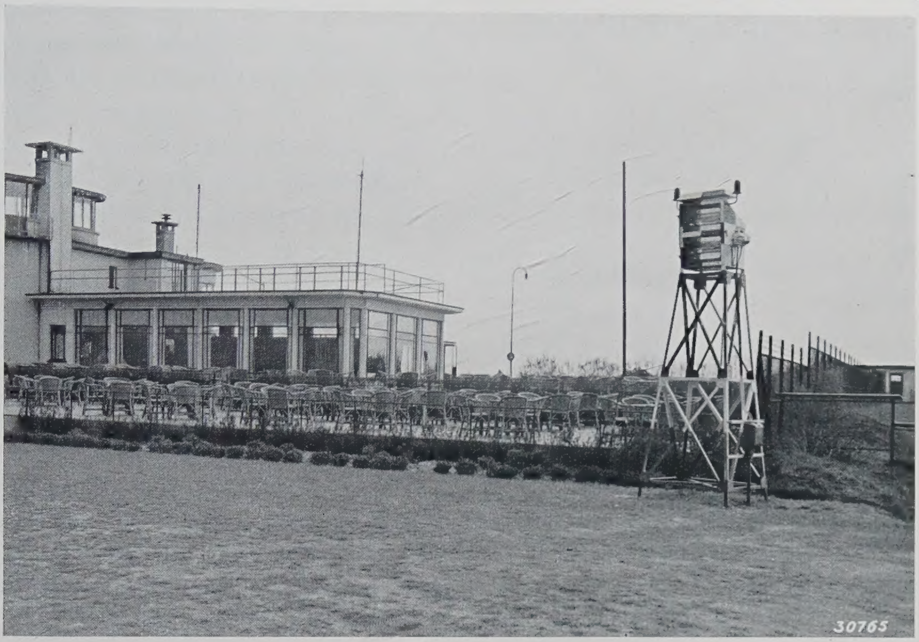

Fig. 6. Landing area floodlight mounted on a simple iron structure. The light consists of two super high pressure mercury lamps placed one above the other in parabolic cylindrical mirrors.

Tests have been made at the aerodrome Schiphol with three water-cooled super high pressure mercury lamps each having a power of 2 000 W (*fig. 8*). These lamps reach their full intensity immediately upon being switched on, so that in this case no measures need be taken for temporary covering of the landing lights. The discharge column is 5 cm long and is again placed along the focal line of a parabolic cylindrical mirror. The light flux per lamp is 120 000 lumens and the maximum brightness is 33 000 c.p./sq.cm, while the maximum luminous intensity is one million candle power per mirror. Since provision is made that the mirrors can be adjusted accurately, with these three lamps placed one above the other, a total light intensity of three million candle power can be attained. The horizontal spread is about 120° like that of the previously described 1 000 W mercury lamps, while the vertical spread is even less than is indicated in fig. 5.

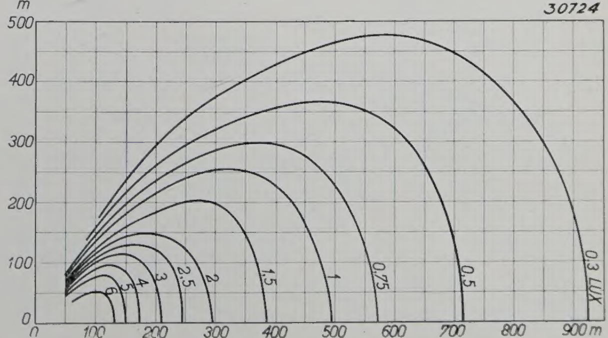

Fig. 7. Curves connecting points on the aerodrome which are equally strongly illuminated by one mercury lamp of 1 000 W.

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[2]) Philips techn. Rev. 1, 215, 1936.

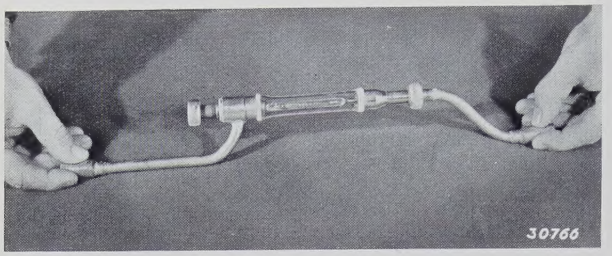


Fig. 8. Water-cooled super high pressure mercury lamp with a power of 2 kW, which gives a light flux of 120 000 lumens.

Landing with poor visibility

In several articles in this periodical the great significance of the ratio for course finding [3]) and for landing [4]) of aeroplanes under unfavourable conditions has been dealt with. Although the radio was initially a reinforcement of the light beacons, at present the illumination must rather be regarded as a supplement to the radio beacon for landing with poor visibility. Due to the development of radio beacons and direction finding stations it is at present quite possible to fly a desired course without seeing the ground. The requirements made of route lights could therefore be lowered. This is, however, not the case in landing on the radio beacon, where in addition to the radio beacon, in order to effect a good landing on the field, an efficient auxiliary illumination is certainly necessary. It is obvious that from economic considerations an attempt will be made to make this auxiliary illumination such that it makes landing in the mist possible in the daytime as well as at night.

As to the visibility of different sources of coloured light in the daytime in hazy or misty weather, L. Bloch [5]) in collaboration with the German railways has carried out practical measurements. He characterizes the density of the haze by the "visibility" S, that is the distance at which during his tests flag poles and telephone poles (close at hand) and factory chimneys and church steeples (far away) could just be seen. Tests were made in mists with a "visibility" of from 200 to 1 400 m, in which the determinations of "visibility" were found to be accurate to about 50 m. Between the luminous intensity I in candle power, the "visibility" S in metres and the distance a in metres at which the differently coloured light sources were just visible, Bloch found the following experimental relation:

$$I = c \frac{a^4}{S^{8/3}} 10^{-4}, \quad \dots\dots \quad (1)$$

where the constant c depends upon the colour. For red light it is 540, while for white, yellow and green light it is 1 080. This means that a light of another colour must be twice as strong as a red light to be seen at the same distance through the same mist. Although it is easier to increase the light intensity of a white light source than that of a red one, it is nevertheless better not to seek the solution in that direction, since for night landings white light is too apt to cause glare. If it is desired to use the same auxiliary illumination for mist landings in the daytime and at night, red is the colour indicated. By giving the auxiliary light a suitable form care must be taken to avoid their confusion with the point obstruction lights and especially with red boundary lights if present. If yellow boundary lights are used, linear red lights may be used without danger for these auxiliary lights.

A strong approach light should be placed in the landing line given by the radio beacon at a distance of about 500 m in front of the boundary of the aerodrome. Tests are being carried out at the present time to find out whether it is desirable to bridge the distance from this light to the same type (placed at intervals of 100 m for example) or by a large number of weaker approach lights. At the point where the line of access marked in this way crosses the boundary of the field it is desirable to install special boundary lights, so-called access lights, which may not project higher above the ground than the boundary lights. The indication of the strip of ground on the field given by the radio beacon (landing area) can in misty weather only be by means of sunken illuminated buttons and not by the landing area floodlights since the latter would only succeed in illuminating the mist in a very disturbing manner.

When yellow boundary lights are used, red should be chosen for approach lights, as shown above, and neon lamps should be used. A low tension neon lamp of 475 W, 1 m long and with a diameter of 4 cm has been successfully used as approach light in a parabolic cylindrical mirror with an opening of 60 cm. The beam of light has a horizontal spread of about 120° and a vertical spread of about 10°. The maximum luminous intensity is 8 000 candle power. In misty weather in the daytime and with a "visibility" of 200 m this approach light is visible from a distance of 670 m according to formula (1). If two or three such neon lamps are placed side by side in the line given by the radio beacon at about 500 m in front of the boundary of the aerodrome, and if their maxi-

[3]) Philips techn. Rev. **2**, 184, 1937.

[4]) Philips techn. Rev. **2**, 370, 1937.

[5]) L. Bloch: Organ Fortschr. Eisenbahnw. **68**, 99, 1931.

mum intensity makes a suitable angle with the horizon (15° for instance) the result is a satisfactory approach light.

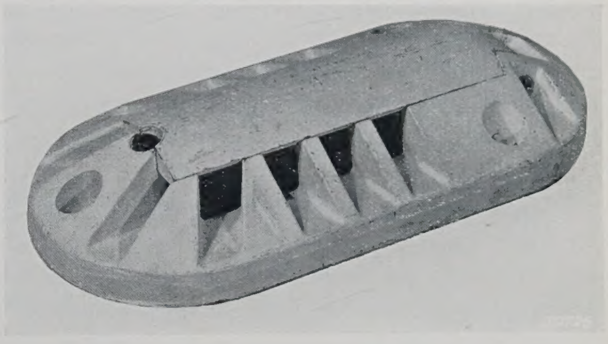
For the lights to be installed at regular intervals between approach light and the boundary of the field, use could be made of high tension neon lamps, which are 2 m long and have a diameter of 1.4 cm. This lamp has an energy of 110 W, and when placed in a parabolic cylindrical mirror with an opening of 15 cm can produce a maximum luminous intensity of about 1 200 candle power. With a visibility of 200 m this light can be seen at a distance of 420 m according to formula (1).

Since in very bad weather it is impossible to make the whole aerodrome visible to the pilot either with the boundary lights or with the landing area floodlights, steps must be taken to accentuate clearly the landing area itself. As explained above this can be done with sunken light sources; if, however, lights were used for this purpose which were entirely flush with the ground, the beams of light would be emitted chiefly in a vertical direction, and the pilot would see only the light which was scattered in a horizontal direction by the mist. Since the machine flys very low over the ground before landing it is desirable to have the beams emitted from the illuminated buttons in directions which make an angle of 20° at the most with the horizon. Therefore these lights, which are installed at intervals of 25 m in two rows along the edges of the landing area, must project slightly above the ground. This, however, is found to offer no difficulties for machines which may ride over them.

In *fig. 9* such an illuminated button may be seen, (*a*) closed, and (*b*) open, which was designed for the "Philora" sodium lamp SO 400. This brings us automatically to the question of the colour which should be chosen for these sunken lights.

On the one hand many aeronautical authorities would like to see yellow sodium lights used for this purpose, since these can be observed under all circumstances. Although the danger of confusion with yellow boundary lights is in this case decreased by the shorter distance between these lights (25 m instead of 100 m) and also perhaps by the different character of their light distribution, such a confusion could be so dangerous that it must be made absolutely impossible in any case by choosing different colours for the boundary lights and the illuminated buttons. For example yellow might be chosen for the latter and red for the linear boundary lights, with special provision against confusion of the latter with red approach lights when present.

On the other hand, however, it is proposed to meet this difficulty by making the illuminated buttons green along the first 300 m of the landing area, white in the middle, with precautions against glare, and red along the last 300 m. This would correspond to the older method of marking the landing area with storm lanterns where green indicates that at that point the landing manoeuvre may be safely begun, while red indicates that it is dangerous to be at that point without having completed the landing. If, however, in order to avoid glare a green-yellow-red system is used, the possibility would again arise that yellow boundary lights might be taken for illuminated buttons. This possibility may perhaps be avoided by extinguishing the boundary lights during a landing on the radio beacon since, as has already been seen, the boundary lights play a much less important part in a heavy mist.



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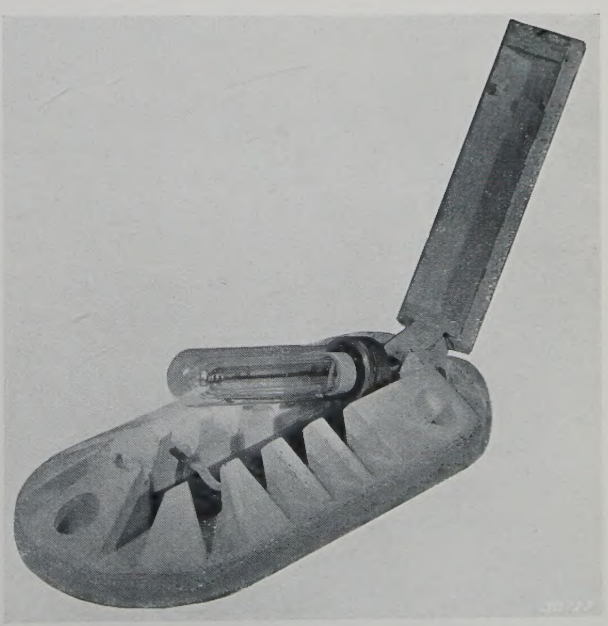

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Fig. 9. Illuminated button closed (*a*) and open (*b*), in which a "Philora" sodium lamp, type SO 400, can be mounted.

BLOCKING LAYER RECTIFIERS

by W. CH. van GEEL.

621.314.63

Certain combinations of materials exhibit a resistance to the passage of current which is dependent on the direction of the current. This phenomenon is given practical application in the so-called blocking layer rectifiers. The action of the blocking layer rectifier is dealt with in this article. Two special kinds of blocking layer rectifiers are discussed in detail, namely the copper-cuprous oxide and selenium rectifiers.

Introduction

The increasing use of alternating current in electro-technology has increased the importance of the problem of converting alternating current into direct current. A choice may be made among various methods, depending upon the strength of the rectified current and the voltage to be rectified, and especially on the requirements made of the character of the rectification.

Rectifiers have been repeatedly discussed in this periodical [1]) which make use of discharge tubes, and particularly of high-vacuum tubes with hot cathodes or gas discharge tubes either with hot cathode or mercury cathode. In this article we shall discuss a quite different type of rectifier whose action is based on the phenomenon that with certain kinds of contacts the resistance to current is many times greater in one direction than in the other.

The first rectifier of this type was discovered by Braun [2]) in 1874 who observed that many crystals, and especially those of metallic sulphides, show a rectifying action when brought into contact with the end of a wire. The resistance to a current from the crystal to the wire can differ very much from the resistance in the reverse direction. Although this phenomenon depends very much upon the condition of the surface of the crystal and can never be reproduced exactly, rectifiers constructed on this principle have played a large part in the development of radio technology as crystal detectors.

Almost simultaneously with Braun's discovery a similar uni-directional resistance was found in the case of copper contacts when one of the copper surfaces had first been oxidized. This phenomenon was found at first to be even less reproducible than the rectifying action of crystals. It was only in 1920 that Grondahl discovered that technically usable rectifiers could be constructed on this principle, which are suitable even for high currents [3]). Such rectifiers are now well known in various types and are called metal or blocking layer rectifiers.

Construction of the blocking layer rectifier

The common characteristic of all blocking layer rectifiers constructed until now is that they consist of two electrodes of different nature which are separated by an insulating layer (blocking layer). For the first electrode a metal is usually taken, often a so-called "rectifying metal", *i.e.* a metal on which a layer of oxide is automatically formed on exposure to the air or on which such a layer can easily be obtained. The oxide layer then serves as blocking layer. Such metals are aluminium, zirconium, titanium, tantalum, niobium. It is, however, by no means necessary that the insulating layer be obtained by chemical treatment of one of the electrodes. Any desired insulating substance can be used as material for the blocking layer, such as resin, sulphur, cellulose, paraffin, paper. The most suitable substances for the other electrode are poorly conducting metallic compounds, such as oxides, sulphides and iodides of metals (for instance copper sulphide, lead sulphide, molybdenum sulphide, cuprous oxide, manganese oxide, copper iodide, etc.). All these substances are semi-conductors.

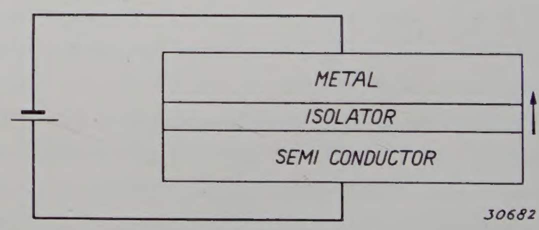

Fig. 1. Scheme for a blocking layer rectifier. The arrow indicates the current direction in which the resistance is generally lower.

Thus for the blocking layer rectifier we arrive at the scheme represented in *fig. 1*: metal - insulator - semi-conductor.

An example of a rectifier of this type is the se-

1) See for example Philips techn. Rev. **1**, 6, 11, 65, 1936.

2) F. Braun, Pogg. Ann. **153**, 556, 1874, Ann. Phys. **1**, 95, 1877.

3) In this connection the reader is referred to the electrolytic rectifier which, as to function, shows some similarity with the blocking layer rectifier. The electrolytic rectifier was discussed previously in this periodical in an article on electrolytic condensers (Philips techn. Rev. **2**, 65, 1937).

lenium rectifier manufactured by Philips. One electrode of this rectifier consists of selenium which is brought into a semi-conducting modification by a suitable heat treatment, whereby at the same time an insulating layer is formed on the surface. For the other electrode an alloy with a low melting point is chosen which can easily be deposited on the insulating layer without the selenium being melted.

Fig. 2a shows how the current of a selenium rectifier (diameter 45 mm) varies as a function of the voltage. The curve, shows that the resistance to currents in the positive direction (which corresponds to the passage of electrons from the metal to the semi-conductor) is on the average much smaller than that for currents in the negative direction.

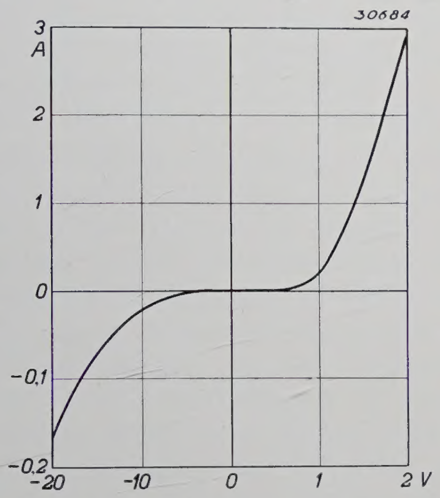

Fig. 2. Current-voltage characteristic of a selenium rectifier with a diameter of 45 mm. *Please consider the entirely different scales for positive voltages and currents and for negative voltages and currents.*

Explanation of the rectifying action

As stated above a blocking layer rectifier consists of two electrodes of different electrical nature which are separated by an insulating layer. This combination exhibits a uni-directional conductivity due to the fact that the electrons can pass over from the metal through the insulator to the semi-conductor, but apparently cannot pass, or only to a much smaller degree, in the opposite direction.

At first sight it seems surprising that this current transport is possible in the insulating material; the insulating power of such a material is based on the fact that the elementary particles of electricity are not mobile in this substance, or at least that they experience great difficulty in moving. With a sufficiently thin layer of an insulating substance this is, however, by no means true.

In order to understand this it must be pointed out that empty space is also an excellent insulator. Between two electrodes in a vacuum, for instance the cathode and anode of an X-ray tube, there must be a field strength of about 10^6 volts/cm before current begins to flow. It is clear that in this case the cause of the resistance cannot be sought in a hindrance of the motion of the charged particles in the space between the electrodes. As soon as charged particles have been successfully introduced into the space between the electrodes there is nothing to prevent these particles from passing from one electrode to the other. The hindrance to the flow of current is thus due only to the fact that energy is necessary to free charged particles from the cathode and bring them into the vacuum. According as the work necessary to do this, the so-called work function, is smaller, the current which flows through the vacuum will be larger.

When instead of empty space there is an insulator between the electrodes, there is no great fundamental difference. It is true that the work function will now depend upon the nature of the insulator, and will often be different from the work function for emission into empty space. The order of magnitude will, however, generally be the same, namely it will correspond to a voltage of a few volts, and this energy is, just as with a vacuum, much more important for the resistance to current than the opposition which the electrons experience in the insulating layer itself.

In order to understand the current-voltage characteristic of a blocking layer rectifier, we must therefore find out what processes affect the passage of electrons from a metal or from a semi-conductor into an insulator. To do this we shall in the following consider in some detail the significance of an insulator and a semi-conductor for the electrons.

The electrons in a metal

A metal like all materials consists of atoms. Each atom is composed of a positively charged nucleus and a number of negative electrons which exactly neutralize the charge of the nucleus so that the whole atom is uncharged.

For example, an atom of copper has 29 electrons, an atom of lead 82 electrons. Most of these electrons circle around the nucleus as planets around the sun; they cannot leave the nucleus and therefore do not contribute to conduction. A small portion of the electrons, usually only 1 or 2 per atom, are, however, not bound to definite orbits but can migrate throughout the whole metal, and the weakest

electric field will already cause them to move in the direction of the field strength.

These electrons are therefore as it were freely moving, with, however, the restriction that they cannot leave the metal. In order to draw an electron out of the metal a definite amount of energy, a certain energy of evaporation as it were, is necessary, which amounts to 2 to 5 electron volts depending on the kind of metal.

The electrons in an insulator

When a solid substance is not a metal, but a chemical compound there are usually no conduction electrons present in it. Due to the formation of the chemical compound new orbits are formed for the electrons, and with chemically equivalent amounts of the elements in the compound the number of orbits is equal to the number of electrons, so that all the electrons are bound. The material is then an insulator. When, however, the number of electrons is greater than the number of orbits, for instance because of the fact that electrons enter the insulator from the outside, these extra electrons are freely moving like the conduction electrons of a metal as explained above.

The electrons in a semt-conductor

When a chemical compound, the oxide of a metal for instance, is not composed of exactly chemically equivalent amounts of the elements but contains too little oxygen for example, not all the electrons are bound and a certain conductivity is retained. The same phenomenon can also occur when the compound contains certain impurities. The number of conduction electrons is, however, much smaller than in a metal (for instance 1/1000 of the number of atoms), and consequently the conductivity is also much smaller. Such substances are called semi-conductors, or, more accurately, "excess" semi-conductors, since the conductivity is caused by an excess of electrons.

If the composition deviates from chemical equivalence in the opposite direction, thus in our case if the oxide, instead of too little oxygen, contains too much oxygen, the number of orbits becomes greater than the number of electrons, so that all the electrons are bound and there are in addition a number of orbits in which no electrons move. There remain therefore a number of atoms which could bind another electron.

In this case also a certain conductivity appears. It is for instance possible for an atom which can bind another electron to receive this electron from its right-hand neighbour. The latter can now receive an electron from its right-hand neighbour and so on, so that the spot where an electron is missing is steadily displaced toward the right. This has exactly the same effect as if a positive charge were moved to the right through the material, in other words, a current flows toward the right. This type of conduction might be called "deficiency" semi-conduction.

After this consideration of the mechanism of conduction in the three components of a blocking layer rectifier we are ready to examine how the conduction takes place in the whole combination.

The action of a blocking layer rectifier

As already stated the resistance of a blocking layer rectifier in the two directions is determined chiefly by the processes which take place in the transition of electrons from the metal or semi-conductor into the insulator.

Thermionic emission

It would seem most obvious to consider this transition as thermionic emission of electrons, *i.e.* as an evaporation of electrons from the emitting material. At a given temperature the electrons have a certain distribution of velocities. The average kinetic energy is much smaller than the work function, and only the speediest electrons can escape. The speed of evaporation is determined by the heat of evaporation which may have different values in the case of the metal and that of the semi-conductor. If it is assumed that the heat of evaporation for electrons (the work function) is smaller in the case of the metal than in that of the semi-conductor, the electrons would show a preference to flow in the direction from the metal to the semi-conductor, in agreement with the observed rectifying action.

Upon consideration of the current-voltage diagram of a blocking layer rectifier, however, it is found that thermionic emission is not capable of accounting for the entire phenomenon. If it were so then, at a given temperature, saturation of the current would occur with increasing voltage and this saturation would be determined by the emission of the electrodes. This phenomenon would have to be plainly noticeable at the voltages which are necessary to cause the rectifier to function. This is found, however, not to be the case: the current continues to increase with increasing voltage. It increases even in both directions more strongly than proportional to the voltage.

The manner in which the current varies with a

given voltage is also not easily explained by thermionic emission. With thermionic emission the current should depend strictly on the temperature and should practically disappear when the rectifier is sufficiently cooled. Actually this is not the case, the current in the direction of passage only decreases slightly with a constant voltage on the blocking layer upon strong cooling and it certainly never becomes zero [4]).

From these discrepancies it may be concluded that the emission of electrons is not caused exclusively by the temperature, but that electrons can be drawn out by the voltage applied independent of the thermal motion. This becomes more easily understandable when it is kept in mind that, thanks to the slight thickness of the blocking layer, very high field strengths occur at the surface of the cathode even at very low voltages.

If for example a blocking layer 10^{-5} cm thick is used, a field strength of 10^6 volts/cm is obtained with a voltage of 10 volts. Moreover there are practically always points on the surface of the electrodes, due to which concentrations of the field occur which can easily increase the field strength locally by a factor 10. Field strengths of the order of 10^7 volts/cm may therefore be expected in the blocking layer rectifier.

Cold emission

When fields of this order of magnitude are applied to electrodes situated in a vacuum it is observed than an electron current occurs which is much greater than the thermionic emission; this current is called "cold emission". Cold emission can be obtained for example by placing the end of a wire as cathode against a plane electrode. Due to the concentration of the field the necessary strong field is obtained at the end of the wire with relatively low voltages. The current density of cold emission may be very high (of the order of 1000 A/sq. cm), the emitting surface in these experiments is, however, only 10^{-7} to 10^{-8} sq.cm., so that the currents observed are nevertheless very small.

An explanation of cold emission was first made possible by applying the new points of view revealed by wave mechanics. We shall not enter into details on this subject, but shall only attempt to show by means of *fig. 3* how the occurrence of this phenomenon can be deduced from the idea that a current of electrons behaves like a train of waves.

[4]) If the current is kept constant, the total voltage on the rectifier increases on cooling, since the resistance of the semi-conductor increases.

In fig. 3*a* the energy diagram is given of an electron which is moving in a conductor toward the surface of that conductor. At the surface the potential energy makes a jump which we have learned to know as the work function of the electron. Outside the surface the energy decreases again due to the electric field, and to the right of point Q it is lower than the energy of the electron which moves toward the surface from the inside.

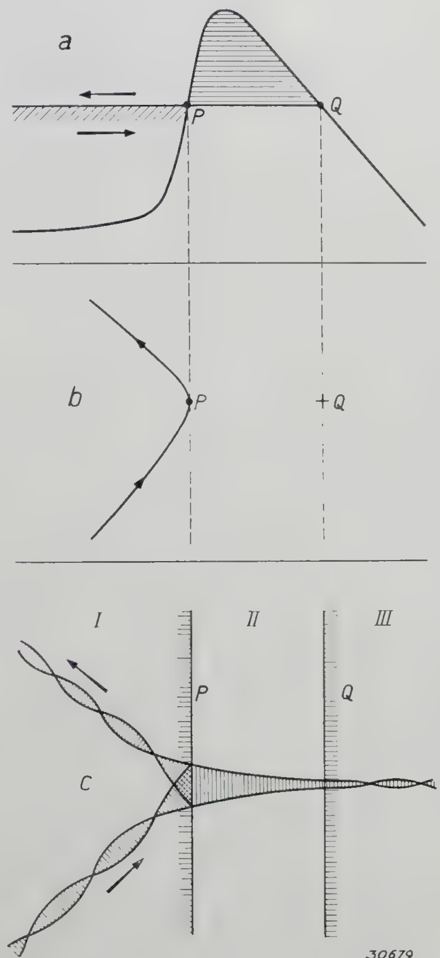

Fig. 3. Explanation of cold emission. *a*) Energy diagram for a particle which, coming from the interior, strikes the surface of a metal. At point P the potential energy (continuous line) is equal to the kinetic energy (broken line). The electron then comes to rest and reverses its direction. *b*) Path of the electron which strikes the surface. *c*) The reflection of an electron which "wishes" to leave the metal and is reflected, exhibits a certain analogy with a light wave which "wishes" to leave a glass body and is totally reflected. If the air gap *II* is narrow enough part of the light penetrates to the second glass body (*III*). In the same way an electron can pass the emission potential if the region between P and Q, in which the potential energy is greater than the total energy, is sufficiently narrow.

According to classical mechanics the electron should be reflected at the potential barrier. The path of the electron "seen from above" is represented in fig. 3*b*. The electron cannot move forward

farther than line P, where the potential energy is equal to the total energy of the electron. The region between lines P and Q is inaccessible to the electron according to the law of the conservation of energy, and it is thus impossible for the electron to be emitted. The electron might exist in the region to the right of the line Q without violating the law of the conservation of energy, but it cannot reach this region without passing through the potential barrier.

When we describe the collision of the electron with the potential barrier in the terms of wave mechanics, the reflection of the electrons means that a total reflection of the waves of matter occurs.

The total reflection of a wave at the boundary between two media does not mean that no oscillation phenomenon at all occurs on the other side of the boundary. We shall demonstrate this by means of an optical analogy. If for example we have two glass blocks to the left of line P and to the right of line Q which are separated by an air gap (see fig. 3), then a light ray incident at a sufficiently large angle φ would be totally reflected at the surface P. In the air gap, however, there is still a certain electric field which decreases exponentially with increasing distance from the boundary P. This results in the fact that reflection is really only total with an infinitely thick air gap. When the thickness of the air gap is not many times greater than the wave length of the light, an appreciable portion of the radiation will be transferred to the second block.

If these considerations are applied to waves of matter which describe the movement of the electron, an explanation is obtained for the phenomenon of cold emission. The length of the waves of matter of the conduction electrons is of the order of 10^{-7} cm. If the thickness of the inaccessible zone is comparable with this wave length, and this is the case with a field strength of 10^6 to 10^7 volts/cm, the material waves will penetrate the potential barrier, which means that electrons are emitted.

When the theory of cold emission is worked out quantitatively, one finds for the current density as a function of the electrical field strength F a relation having the following form:

$$i = AF^2\, e^{-B/F}, \quad \ldots \ldots \quad (1)$$

where B is proportional to the work function to the 3/2 power.

The current in the direction of rectification can be approximately described by a formula of the form of equation (1) if it is assumed that the field strength F is proportional to the voltage V on the rectifier. The relation between F and V is difficult to give precisely, because the thickness of the blocking layer is not usually everywhere the same, and moreover it is not known to what degree the field strength is raised by the presence of projecting points.

The higher resistance to current in the direction opposite to that of rectification must be explained by assuming that in this direction a much smaller cold emission occurs. It may then be expected that other manners of current passage, such as thermionic emission and electrolytic conduction of the blocking layer will play a relatively greater part. It is also found that in the direction opposite to that maximum flow equation (1) does not hold so well and that the shape of the I-V curve found is strongly affected by the way in which the rectifier is constructed.

The fact that the cold emission of the metal plate is different from that of the semi-conducting plate may be due to various reasons:

In the first place the electrons in a semi-conductor, are much less mobile than in a metal. Consequently much fewer electrons will strike the surface per second, so that the number of electrons which leaves the surface per second will be much smaller with the semi-conductor than with the metal.

In the second place cold emission just as thermionic emission depends upon the work function, which may be different in the case of a semi-conductor and a metal.

In the third place, depending on the method of construction, it is possible that sharper points project from the surface of one electrode than from that of the other, so that at a given voltage stronger fields occur at the surface of one electrode than at the surface of the other.

The first effect results in the fact that electrons can pass more easily from the metal to the semi-conductor, while the second and third effects may favour one direction or the other according to the circumstances.

Each of the three effects may of itself be large enough to explain a rectifying action of the order of magnitude observed. It is possible that in technically important blocking layer rectifiers there is a collaboration of different phenomena which cannot be separated from each other experimentally.

The construction of blocking layer rectifiers

The first blocking layer rectifier which had practical significance also for higher currents consisted of a combination of copper and cuprous

oxide. To make a cuprous oxide rectifier, a plate of pure copper is heated in air to a temperature of about 1 040 °C. The copper oxidizes in air and becomes covered with a layer of cuprous oxide, Cu_3O. This cuprous oxide by itself is not a semi-conductor, but an insulator. By means of a suitable heat treatment the cuprous oxide can, however, be made to take up oxygen from the air and thus become semi-conducting.

From the method of preparation there is no evidence of the existence of a blocking layer between the copper and the cuprous oxide. The fact that such a blocking layer is present may be explained as follows. We saw above that pure cuprous oxide forms an insulator and only obtains its conductive properties by an excess of oxygen. At the boundary surface of the cuprous oxide and copper a certain diffusion of atoms takes place, so that the composition changes gradually from Cu_2O with excess oxygen to pure copper. In this case, however, there must be a certain layer present in which the cuprous oxide has exactly the stoichiometrical composition, and this layer forms the blocking layer. The cuprous oxide rectifier thus corresponds to the scheme metal-insulator-semi-conductor.

As already mentioned a blocking layer rectifier has been developed by Philips in which selenium is employed as semi-conducting material.

Selenium is a substance which occurs in various modifications. When powdered selenium is fused, a glassy mass results which has a high specific resistance. When this mass is brought to a temperature between 100 and 220° C the selenium passes over into a grey crystalline modification which is more conducting, and which in thin layers is useful as semi-conducting electrode of a blocking layer rectifier. Selenium is always used in the form of a thin plate on a metal base plate because it is so brittle.

The molten selenium is deposited on the base plate and pressed to a thin layer. Then the above-mentioned heat treatment is applied and the grey modification is obtained. At the same time a blocking layer is formed on the free upper surface of the selenium (thus not between the selenium and the base).

After cooling a thin layer of metal is deposited on the blocking layer. An alloy of tin, cadmium and bismuth with a low melting point is used. This layer is connected to one supply wire by means of a contact spring. The other contact is made on the base plate.

Properties of the selenium rectifier

The current-voltage characteristic of the Philips selenium rectifier has already been given in fig. 2. The current in the direction of rectification can be approximately represented for voltages below 1 volt by a formula of the following form:

$$i = A V^2 e^{-b/V},$$

where A and b are constants. At higher voltages there are deviations from this formula because the resistance of the selenium layer at higher current causes a voltage drop which may not be neglected.

In the direction of least flow of current the remarkable situation occurs that upon application of the voltage it takes some time before the current reaches its final value. This effect is already noticeable upon comparison of the current-voltage characteristics for direct voltage and for an alternating voltage of 50 c/s, especially when the rectifier has been working for some time.

The characteristics reproduced refer to room temperature. Upon increase of temperature the current in both directions increases. In the direction of rectification the increase of current per degree of temperature increase is about 1 per cent, in the other direction it is an average of 5 to 10 per cent.

The permissible current strength for continuous action through the blocking layer rectifier is 300 mA in the direction of rectification, which corresponds to about 0.9 volt; in the other direction about 20 volts are permissible. At too high a voltage on the blocking layer breakdown may occur. This usually results in the burning away of the projecting points which caused the breakdown. This has, however, no unfavourable effect on the action of the rectifier, since no permanent destruction (short circuit) of the blocking layer results. The cuprous oxide rectifier is much more sensitive to breakdown. In this case breakdown always leads to permanent short circuit.

In addition to breakdown, overheating may also occur upon overloading the rectifier, with the result that the metal electrode melts. In that case it may happen that the contact springs push through the blocking layer and cause permanent short circuit. In most cases, however, the selenium rectifier can withstand even this severe test.

A SIMPLE APPARATUS FOR SOUND RECORDING

by K. de BOER and A. Th. van URK.

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A simple instrument is described which makes it possible for the layman to make sound records of very satisfactory quality. The sound is recorded on discs which can be played on an ordinary gramophone. The choice of system and the construction of the recorder are discussed in detail. The recorder has a flat frequency characteristic between 60 and 4 500 cycles/sec and only requires a driving power of 0.6 W. Therefore no other amplifier is necessary for the microphone currents than the low-frequency part of a radio receiving set. This fact makes the instrument particularly suitable for use in music and elocution schools and in the teaching of languages. In conclusion particulars are given for the operation.

While the possibility of recording visual impressions by means of photography has found wide application in the hands of the layman, the possibility of recording acoustic impressions has found relatively little application outside sound film and gramophone studios. There are nevertheless many cases where it would be very useful to be able to record sound. Musicians and actors might in this way be enabled to criticize their own production without being compelled at the same time to concentrate upon the performance. The same is true in the case of speakers engaged in preparing a speech. It is a well known fact that while speaking one hears one's own voice quite differently from the way in which the audience hears it, due among other factors to the conduction of the sound through the bones of the ear. The pedagogical possibilities are very great for music and elocution schools. The teaching of languages may also profit very much from good records of speech, as is proved by the existence and results of teaching systems based solely on gramophone records.

At the same time sound records may also be of interest to the private person, for recording important telephone conversations, for correspondence by means of gramophone records or other similar purposes.

A recording apparatus which is to be suitable for the applications mentioned must be simple in operation, while at the same time the quality of reproduction must be satisfying. In the following we shall describe a simple instrument, which was developed in this laboratory and which makes it possible for non-technical persons to make sound records of very satisfactory quality, which can later be reproduced in the same way as ordinary gramophone records.

Choice of the recording system

All the mechanical systems of sound recording [1]) have one common feature: a cutting tool moving in the rhythm of the sound vibrations cuts a sound track in a more or less soft material. This material may be deposited on a cylinder, as was the case with Edison's phonograph and as is still customary with dictaphones, or it may be on flat discs. The construction of the recording apparatus can of course only be suitable for one of these forms. The instrument was designed for recording on discs, since the intention was that one should be able to reproduce the recorded sound on an ordinary gramophone.

The sound track on the record can be modulated in two ways: the depth of the groove cut may vary in the rhythm of the sound vibrations (Edison recording), or the vibrations may be reproduced as the transverse wave-like form of the groove (Berliner recording). Edison recording has the advantage that the spirals of the groove may lie very close together, while with Berliner recording a space must be left between the spirals which is equal to twice the amplitude of the greatest deviation occurring. With Edison recording therefore it is possible to obtain a longer playing time of the record with the same diameter of the disc. Over against this are the disadvantages that the recording apparatus for this system is more difficult to construct and more easily leads to distortion. At the present time gramophone records are made almost exclusively by the Berliner system, and the pick-ups of ordinary gramophones are constructed for this system. The recording apparatus therefore has also been designed for "Berliner" recording.

There are moreover two alternative methods of recording, depending on whether the groove is to be cut from the centre toward the edge or from the edge toward the centre of the disc. The last-

[1]) We may here neglect the optical system of sound recording such as is used for sound film, since it is too elaborate and expensive for the purpose in view.

mentioned system is the customary one, so that the automatic stopping switch which most gramophones possess is always designed for this manner of recording. The system however has the disadvantage that care must be taken during the cutting process that the cutter does not touch the shaving previously cut out. The shaving, if it is not removed, lies on the disc in a circle which — probably due to shrinkage — has a diameter somewhat smaller than that of the groove cut. Contact between cutter and shaving might lead to damage to cutter or groove. When the groove is cut from the centre toward the edge, this difficulty cannot arise, but on the other hand in that case the automatic stopping switch can also not be used when the record is played. In order to leave it to the user to decide which factor is more important for him, greater ease in cutting or greater convenience in playing, our recorder has been so constructed that by interchanging a few parts it is possible to pass over from one method of cutting to the other.

Another disadvantage of cutting from the edge toward the centre is that the high tones are apt to suffer. Good reproduction of the high tones depends upon whether the point of the needle with which the record is played can easily follow the waves of the groove. To do this it is necessary that the radius of curvature of the waves shall be greater than the radius of the point of the needle. The point of the needle suffers considerable wearing down even after playing one record of hard material like the wax records now on the market. The point of a new needle has a diameter of about 50 μ, at the end of the record it has become blunter, however, and is for instance 100 μ thick. The radius of curvature of the waves of the groove is, at a definite recorded frequency, proportional to the distance from the centre of the disc, thus in the outermost grooves it is 2 to 3 times as great as in the inner grooves. It is therefore best from the point of view of reproduction to begin with the new, fine needle point where the radius of curvature of the groove is the smallest, namely at the inner grooves.

The sound recorder

The cutter is driven according to the electromagnetic method. *Fig. 1* shows diagrammatically the construction of the sound recorder. The armature is situated in the field of the permanent magnet between two pole pieces, which are excited by the magnet *NZ*. The motion of the armature about the torsion axis *T* is caused by the alternating field which is excited by the alternating current flowing through the coil *Sp*. If the current (for instance that amplified in the low-frequency part of a radio set) from a microphone into which some one is speaking is sent through the coil, the armature oscillates in the rhythm of the sound to be recorded. The cutter is attached to the armature, and upon oscillation of the armature it cuts an undulating groove in the record rotating beneath it.

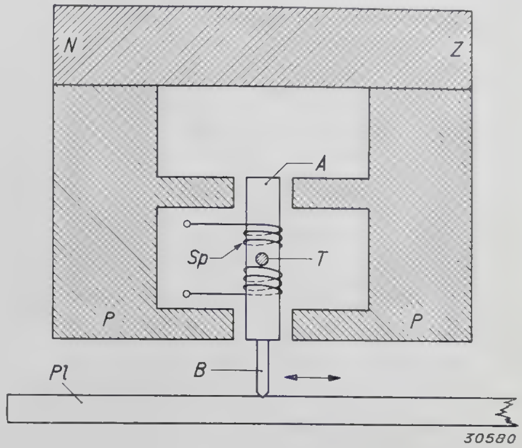

Fig. 1. Diagram of a sound recorder according to the electromagnetic principle. *NZ* magnet, *P* pole pieces, *A* armature, *Sp* coils through which flows the microphone current which varies in the rhythm of the sound vibrations. *B* cutter which cuts a transverse wavelike groove in the moving record *Pl* upon the oscillation of the armature.

We shall now calculate the amplitude taken on by the cutter during the oscillation of the armature. With a sinusoidal alternating field having the peak value ΔH a varying couple is experienced by the armature which has the peak value

$$K = \frac{1}{2\pi} H_0 \, \Delta H \cdot O \cdot r_a, \quad . \; . \; . \quad (1)$$

where H_0 is the permanent field in the air gap, O the area of the surface of the pole pieces and r_a the length of the lever upon which the forces making up the couple act. Under the influence of this varying couple the armature oscillates, as long as the frequency ω of the alternating field is small with respect to the resonance frequency ω_0, with an angular amplitude K/c, when c is the resistance to torsion of the clamping point at T. The amplitude a of the cutter which is fastened at a distance r_b from the turning point becomes

$$a = r_b \cdot K/c \, . \quad . \; . \; . \; . \; . \; . \quad (2)$$

The torsion resistance c may be expressed in the resonance frequency ω_0 of the oscillating system and the moments of inertia I_a and I_b of the armature and the cutter with the help of the relation:

$$\omega_0 = \sqrt{\frac{c}{I_a + I_b}} \quad . \; . \; . \; . \; . \; . \quad (3)$$

For a we obtain the equation

$$a = k \, \frac{H_0 \, \Delta H}{{\omega_0}^2} \quad . \; . \; . \; . \; . \; . \quad (4)$$

with the coefficient

$$k = \frac{1}{2\pi} \cdot \frac{r_b \cdot O \cdot r_a}{I_a + I_b} \quad . \quad . \quad . \quad . \quad (5)$$

In practice it is important to make the sensitivity of the cutter high, *i.e.* to be able to obtain the desired deflection of the armature with as small an amount of electric energy as possible. In order to do this, in the first place the numerator of (4) must be large. The alternating field ΔH is proportional to the coil current; the proportionality factor depends upon the so-called alternating current permeability μ of the material in the whole magnetic circuit. The value of μ in the pole pieces, however, depends once more on the magnetic induction which (aside from leakage) is equal to the field H_0 in the air gap. For a certain value of H_0 the product $H_0 \Delta H$ reaches a maximum. H_0 is adjusted to this value by a suitable choice of the dimensions of the magnet.

Furthermore a large amplitude a could be obtained according to equation (4) by keeping the resonance frequency ω_0 low. In this case however there are other important considerations to which we shall return later.

Finally a may be enlarged by making the factor k in (4) large. According to equation (5) it is in the first place desirable that the moments of inertia I_a of the armature and I_b of the cutter be made as small as possible. The quantities of length which also occur in k are partly determined by structural considerations. For the case where $I_a \gg I_b$, however, another general conclusion may be drawn from equation (5). Since I_a has the dimensions of a density times a length to the fifth power, k has the dimensions of the reciprocal of a length times density. Therefore if in equation (4) both $H_0 \Delta H$ and ω_0 are considered constant, it is clear that a becomes greater when the cutter as a whole and in all its parts is reduced proportionally in size. A limit is set to this reduction by two conditions:

1) The armature must have certain minimum dimensions in order to have the power necessary to overcome the resistance of the gramophone record (Moreover it is not permissible to reduce the size of the cutter at will with the whole system, so that the condition that $I_a \ll I_b$ for the above consideration is no longer fulfilled).
2) The air gap must remain large with respect to the amplitude of the armature, since otherwise a non-linear distortion occurs in the recording. (The deflection of the armature is then no longer proportional to the coil current).

As to the first condition, the reduction in size of the whole recording apparatus could have been carried much further than was actually done in the construction. No advantage has been taken of this possible gain in sensitivity in order to continue to satisfy the second condition as well as possible. The sensitivity obtained is in any case quite sufficient for practical cases as we shall see in the following.

Comparison with the sound recorder of the Philips-Miller system

It is interesting to compare the sound recorder of the instrument with that of the Philips-Miller system [2]). The latter system of sound recording on a special film has been developed to satisfy to the extremely high requirements of modern broadcasting. In addition to this it offers special advantages for sound film. With the Philips-Miller system the sound is recorded as a groove of varying width on a film. This groove is obtained by means of a wedgeshaped knife which is pressed by the oscillating armature more or less deeply into the moving film. While the two sound recorders show considerable similarity there is one essential difference: in the Philips-Miller system it is the armature itself which must provide the force to overcome the resistance of the material and prevent the cutter being pushed out of the material. It is the variation of this force which provides the modulation. With the described recorder on the other hand, where a groove of a constant depth and width is cut, the force which holds the cutter in the material is constant and can therefore be obtained by means of a weight attached to the cutter.

The required force of the armature in the recorder of the Philips-Miller system is thus many times greater than with the recording of discs. If it is tried to obtain the required sensitivity by reducing the size of the whole recorder the limit prescribed by the force attainable is much sooner reached with the Philips-Miller system than the limit prescribed by the requirement of linearity. With recording on gramophone discs, however, the situation is just the reverse and the limit in this case lies at much more reduced dimensions.

Construction of the Recorder

Fig. 2 is a photograph of two sound recorders. The left-hand one has been opened. To the left

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[2]) R. Vermeulen, The Philips-Miller system of sound recording, Philips techn. Rev. 1, 107, 1936; A. Th. van Urk, The sound recorder of the Philips-Miller system, Philips techn. Rev. 1, 135, 1936.

may be seen the magnet with the pole pieces. The armature is provided with a hole in which the cutter is set and fixed with a screw. The armature

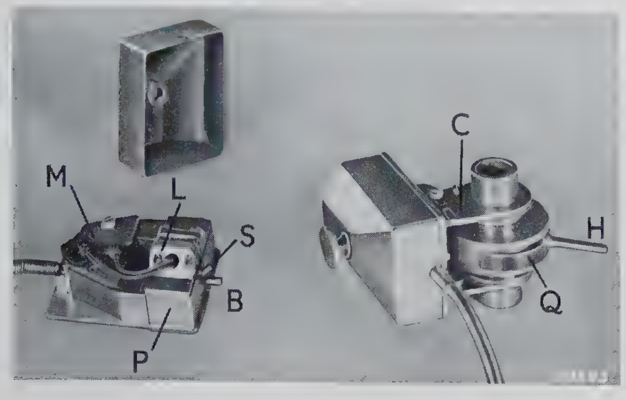

Fig. 2. Two examples of the sound recorder. The one on the left which is open shows the magnet M, the pole pieces P with the side blocks L between which the armature is clamped and the cutter B which is fastened into the armature with the screw S. The recorder on the right is mounted on the bridge C with which the displacement during the cutting is obtained.

is sketched in *fig. 3*. The armature proper is connected by two rods to the plates K, which are clamped between the side blocks L of the pole pieces, see *fig. 2* (the lower pair of side blocks is not visible there but may be seen in *fig. 5* on the extreme right). The front surfaces of the pole pieces with side blocks, as well as the armature block drawn in fig. 3, are ground plane. By laying copper plates of a definite thickness between the plates K and pole piece blocks L while the armature is being clamped in, an air gap is obtained with accurately defined dimensions.

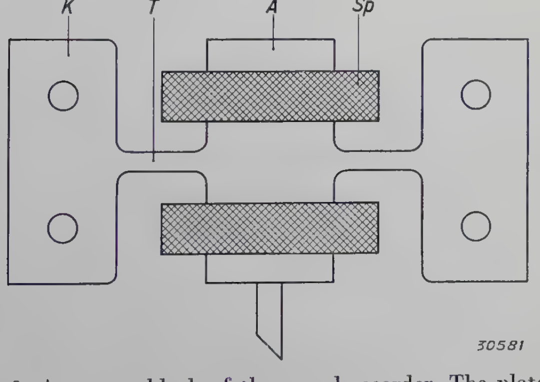

Fig. 3. Armature block of the sound recorder. The plates K which are clamped between the side blocks L (figs. 2 and 5) of the pole pieces bear the armature proper A by means of the rods T which serve as torsion axes. Sp coils.

Transport arrangement

The cutter is mounted on a bridge (C in fig. 2, on the right), which moves slowly over the disc during the cutting in such a way that the cutter follows a diameter of the disc. The whole arrangement is shown in *fig. 4*. Details of the transport system are shown in fig. 5. After the disc to be cut has been laid on the turn-table, the flange F is set on the centre of the disc and fastened tight with a setting screw to the axle of the motor. A worm on the axle of the flange turns the screw shaft W *via* a pinion. The shaft W has a bearing outside the disc consisting of a bronze pin screwed into a support fastened to the base plate of the apparatus. The support is adjustable in height in order to be able to set the shaft exactly parallel to the disc to be cut.

When the cutting is completed, the bridge with the recorder must be brought back to the starting point of the groove. For this purpose the bridge is constructed as follows. On either side it has two bushings (best seen in fig. 2) which slide freely along the shaft. The recorder is fastened to the piece joining the two bushings. Between the two bushings is a half nut which is pressed by a spring (Q in fig. 2) into the screw of the shaft so that the recorder is carried along. By means of a small lever the nut can lifted from the shaft so that the recorder can then be moved freely along the shaft.

The axle of the flange F must be exactly perpendicular to the disc, in order not to oscillate upon turning. The flange therefore does not rest directly on the disc to be cut, but has three points of contact with it which are fastened to the rear side of the flange. If the disc has a slight irregularity, which is often the case, then by turning the flange slightly it is always possible to find a position where the axle of the flange is accurately in a straight line with the axle of the motor.

A circle of small brushes is fastened to the flange which remove the shaving if it is guided toward them at the beginning of the cutting process. This precautionary measure, as explained above, is only necessary when the groove is cut from the edge toward the middle. In cutting from the middle toward the edge the shaving may be disregarded. If it is desired to use the latter method, only the screw shaft W and the nut in the bridge need be exchanged.

Driving power of the record

During the cutting process the cutter must overcome the resistance of the material of the disc, which exercises a retarding couple on the motor. The magnitude of this retardation depends upon the quantity of material which must be cut at each moment, and it is clear that this is greater the greater the deflections of the groove, *i.e.* the louder the passage to be recorded. It is essential that the varying couple should have no effect on

Fig. 4. The recorder in action. At the centre and outer edge of the record, shorter recordings have already been made. The shaving from the grooves just cut may be seen lying on the record in a circle slightly smaller than the groove (normally the shaving is removed by the brushes at the centre). On the left, the pick-up for reproduction. Right foreground the switch. Along the circumference of the turn-table may be seen the divisions which serve for checking the number of revolutions per minute. Under the turn-table the motor is suspended on springs.

the number of revolutions per minute of the motor, since otherwise the height of the tone of the sound to be reproduced rises and falls to the same degree (this is a well known and very disturbing effect especially in the case of piano music). The motor must therefore be sufficiently strong. If the turn-table is given a large moment of inertia so that it can act as fly-wheel and take up to some extent the variations of the retarding couple, a motor with a couple of 5 000 gcm is sufficient.

In the reproduction of a record the forces acting are much smaller than in the cutting. In this case therefore a weak motor is sufficient and no fly-wheel is needed. Ordinary gramophone motors

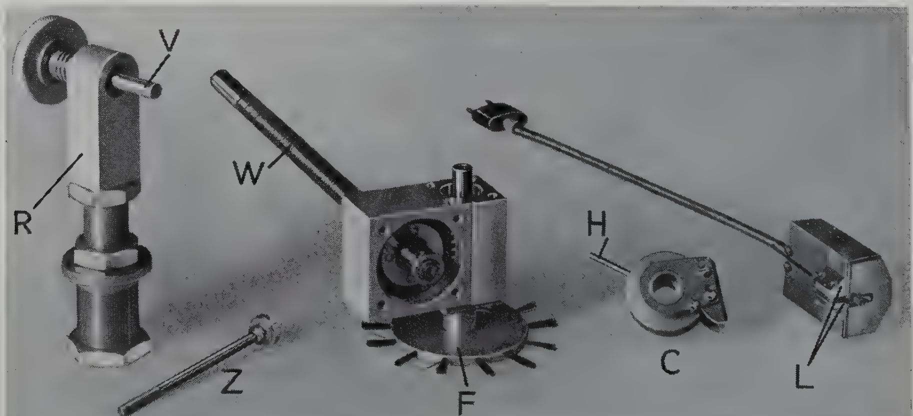

Fig. 5. Parts of the transport arrangement. F flange which is set on the record to be cut; Z setting screw; W screw shaft which *via* a worm and pinion (visible in the opened housing) is driven by the motor axle. C bridge which carries the recorder (extreme right) and which is transported by the screw shaft W by means of a half nut (visible through the hole). The nut is pressed by a spring (Q in fig. 2) into the screw of the shaft W, it can however be lifted by means of the lever H in order to be able to move the bridge freely along W. V the pin which is screwed into the support R and forms the outermost bearing of the shaft W.

only have a couple of about 800 g cm. This makes it absolutely impossible to cut satisfactory records by means of an ordinary gramophone.

An additional requirement is that the motor may not transfer any vibrations to the turn-table, since otherwise these vibrations would also be recorded on the record while the sound was being recorded. The motor axle is therefore coupled to the axle of the turn-table *via* an intermediate section of rubber. In order to prevent any vibrations from the motor from reaching the base plate of the apparatus and from there *via* the bearings reaching the turn-table, the motor is hung on the ground plate with rubber rings at points of contact.

In order to be able to check the number of revolutions per minute of the motor the circumference

to the recorder for all frequencies. According to equation (4) the amplitude a is proportional to ΔH, and therefore also proportional to the coil current. The impedance of the armature coils is determined chiefly by their self-induction; the current, and therefore also a, is then proportional to $1/\omega$ at constant voltage.

Equation (4) only holds as long as the frequency ω lies far below the resonance frequency ω_0. If the frequency is allowed to increase until it reaches the neighbourhood of ω_0, the deflection increases sharply and resonance occurs. Care must therefore be taken that the resonance frequency of the armature is sufficiently high above the highest frequency of the sound vibrations to be reproduced. On the other hand, however, as we have

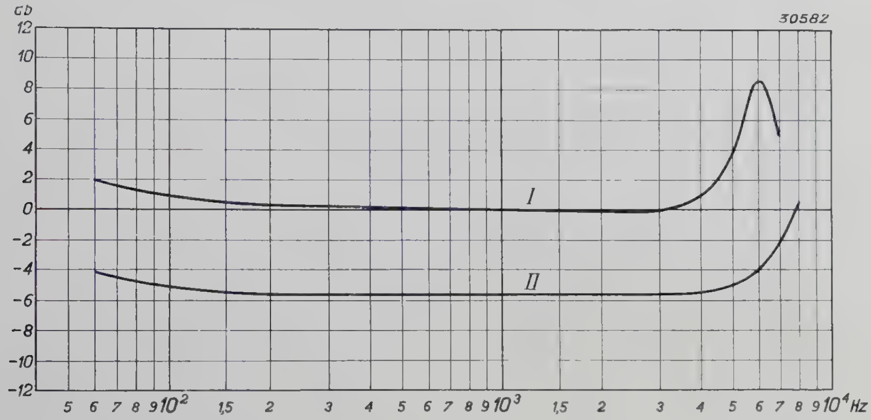

Fig. 6. Frequency characteristics, recorded during the cutting process. The velocity amplitude ω_a is plotted as a function of the frequency $\nu = \omega/2\pi$. Curve *I* is for the ordinary recorder, curve *II* for a special recorder with a lower sensitivity.

of the turn-table is marked off in certain divisions. If these are examined by the light of a source which is modulated with 100 c/s (an ordinary electric lamp burning on an alternating current main), then, due to the stroboscopic effect the turn-table appears to be stationary when the motor has the correct number of revolutions per minute (78 r.p.m.).

On the turn-table there is also a pick-up (fig. 4, left), so that the record can immediately be played.

Frequency characteristic of the sound recorder

For the cutting of gramophone records it is desirable that the velocity amplitude ωa of the armature should be independent of the frequency ω of the current through the armature coils [3]). This is attained by supplying a constant voltage

[3]) This is because of considerations given in the article by Vermeulen, quoted in footnote 2, on p. 108.

seen, the resonance frequency must be low for the sake of sensitivity. (according to formula (4) the sensitivity is inversely proportional to $\omega_0{}^2$). A compromise must therefore be found such that not only the sentivity but also the shape of the characteristic satisfy reasonable requirements.

In the use by the layman, simplicity of operation is important. If it is assumed that as amplifier for the microphone currents to be supplied to the recorder a radio set will be used, then in connection with the available power, the resonance frequency of the armature may lie at about 6 000 c/s. The recording instrument has been constructed with this in view. In cutting into the record an extra resistance due to the resistance of the material of the record is added to that of the armature so that the resonance frequency in practice lies about 10 per cent higher. In order to make the frequency characteristic flat as long as possible, up to very close to the resonance frequency, copper cores

have been introduced into the armature coils. The eddy current loss resistance hereby caused increases with ω^2 and begins to be appreciable just at those frequencies where the amplitude would begin to increase gradually due to resonance.

In this way a frequency characteristic is obtained which is flat in the region from 60 to 4 500 c/s. In *fig. 6* (curve *I*) the velocity amplitude ω_a at constant voltage obtained during cutting is given as a function of the frequency $\nu = \omega/2\pi$. As may be seen the deviations from the flat curve are smaller than 2 dB in the frequency region mentioned, and this deviation is still imperceptible for the ear.

If there is no objection to the use of an extra amplifier so that more power is available, the resonance frequency may be made higher. This is desirable for scientific investigation, for example, where very high requirements are made on the quality of reproduction. For this purpose a sound recorder is constructed with a resonance frequency of 8 500 c/s. Since according to equation (3) ω_0 increases with increasing stiffness c of the clamping point of the armature, the higher value of ω_0 is obtained simply by making the torsion rods T (fig. 3) somewhat higher. The frequency characteristic of this recorder is given in fig. 6 as curve *II*; it is flat between 50 and 6 500 c/s. Since the deflection of the armature according to equation (4) is proportional to $1/\omega_0^2$, in this case twice as high a current through the armature coils is necessary for the same deflection as was the case with the first recorder described.

Fig. 7 gives the amplitude of the armature as a function of the current in the coils. The curve was recorded at 200 c/s, since in the region of low frequencies there is the greatest chance of non-linear distortion. The largest amplitudes occur in this region. It may be seen from the figure that the amplitude varies with the current according to a practically linear relation.

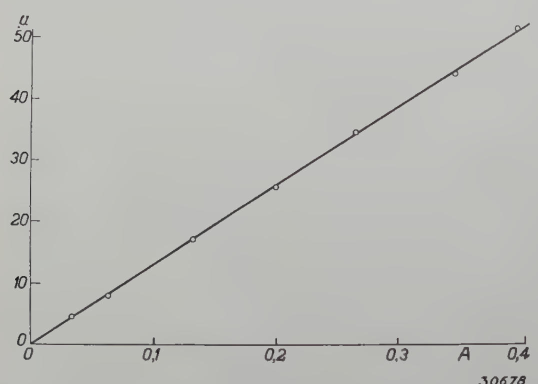

Fig. 7. Amplitude of the armature of the recorder as a function of the current in the armature coils, recorded at 200 c/s. The relation is fairly approximately linear.

The operation of the recorder

As already stated, it was assumed that a radio set would be used as amplifier. Receiving sets with a triode or an inverse feed-back pentode as end valve (the Philips sets of recent years belong to this category) give an output voltage independent of the frequency such as is required for the instrument. The impedance of the recorder (5 ohms at 1000 c/s) is so chosen that it can be connected directly to the extra loudspeaker terminals of the Philips sets. The necessary energy is about 0.6 W, which can be supplied by a good set with less than 5 per cent distortion.

The microphone which picks up the sound to be recorded is connected to the terminals of the radio set intended for connection to a pick-up. *Fig. 8* shows the complete arrangement. The voltmeter, which may be seen next to the recorder, is connected in parallel and serves for controlling whether or not the permissible amplitude (about 50 μ) is exceeded. There is a mark on the scale indicating the greatest permissible deflection. The instrument reacts quickly enough to indicate the peaks in the sound which might just become dangerous.

Ordinary gramophone records are always recorded at low frequencies with constant amplitude (instead of an amplitude increasing with $1/\omega$) in order not to reach very great amplitudes, and thus make a large distance between the grooves necessary. Ordinary pick-ups are therefore adapted to this variation of the amplitude with the frequency, and in cutting records with our instrument this must be taken into account: if the cutting were carried out with constant velocity amplitude everywhere, then in the reproduction with ordinary pick-ups too many low tones would be obtained. With this in mind it is advisable to set the speech-music switch of the receiving set being used as amplifier in the "speech" position. The output voltage for the low frequencies below about 300 c/s is hereby decreased.

The ordinary kinds of cutters and blank records found on the market are suitable. With steel cutters two records can generally be made (thus both sides of one disc). Saphire cutters are worn out only after 20 to 30 recordings [4]). The records are usually made of glass on which a thin layer of wax or gelatine is deposited. The cutter is so designed that it can overcome the resistance of the softest material by its own weight. With harder materials it must be weighted by the addition of small weights.

The life of the finished records, like that of ordinary gramophone records, depends very much

[4]) Diamond cutters are also used which last longer but are expensive and quite brittle.

upon how they are played. If a good electric pick-up is used which is light and in which the needle can be moved by very small forces, wax or gelatine can be played about 100 times. When a mechanical pick-up is used, such as that of a portable gramophone, the records wear out more rapidly because of the required greater forces on the needle; the life of the record is then limited to being played about 30 times. Because of the greater forces necessary with the mechanical pick-up a stronger motor is also necessary for reasonably satisfactory reproduction.

Fig. 8. Complete set-up for sound recording. From left to right: radio receiving set serving as amplifier, voltmeter for controlling the amplitude, recorder with turntable. The carbon microphone stands in the background.

SEVERAL PROBLEMS OF X-RAY FLUOROSCOPY

by B. van DIJK.

621.386.8

Several problems are dealt with in this article which are connected with the protection against X-rays and the visibility in the X-ray picture of certain abnormalities to be detected. Both problems were encountered in the examination by X-ray fluoroscopy of large numbers of persons as carried out regularly in the Philips concern for the detection of cases of tuberculosis, but they may also be important in other connections. Special attention is paid to the methods of investigation developed for estimating the security against the rays and the resolution of the fluorescope image, while in conclusion a number of results of the investigation are given.

When in 1932 a systematic X-ray examination of the personnel of the Philips factories was begun for the purpose of early detection of cases of tuberculosis [1]) various problems were encountered which were important enough to warrant further study. Two of these problems, which are also important in other applications of X-rays, will be discussed briefly, namely first the question of how it is possible to protect persons who work daily with X-rays against the harmful effects of the rays, and second the question of the size and shape of abnormalities (of the sort to be detected) which can be observed in the X-ray image which is always of quite low intensity.

Both questions are very complex. The measures for protection against X-rays will be quite different in the case of a doctor, for instance, from those necessary in the case of the personnel in a factory making X-ray tubes. As to the second question, the visibility of an abnormality will depend in the first place on its size and shape and on the difference in absorption of X-rays between the abnormality and the healthy tissue. But in addition the position of the abnormality in the body is very important, because it makes certain requirements as to hardness of the X-rays which must be used in order to penetrate the body at the point where the abnormality is situated.

We shall not attempt to reach any general conclusions on the problems mentioned, but shall deal mainly with the methods which have been developed for the investigation of these problems.

Protection against X-rays

Absolute protection against X-rays is impossible because every material transmits a certain percentage of X-rays. On the other hand it has been found from experience that a person can endure a certain amount of X-radiation without harm. This amount, the so-called tolerance dose, depends upon the intervals between exposures. The problem is to protect the doctor to such an extent that the amount of X-rays to which he is exposed remains below the tolerance dose. Since the tuberculosis examination in the Philips concern usually amounts to the carrying out of 50 to 60 fluoroscope examinations per day by the same examiner, it was necessary to find out whether this could be continued without harmful results. Although the examiner is protected from the direct rays outside the effective beam of radiation by the metal container of the tube, and from the direct rays in the effective beam as well as most of the secondary rays by the lead glass of the screen and in addition by a shield of lead rubber, there was a possibility that secondary rays might strike parts of the examiner's body, and when a large number of examinations were carried out these secondary rays might exceed the tolerance dose.

In order to measure the undesired X-radiation, use was made of the fact that the blackening of an irradiated film with a given method of developing is a measure of the size of the dose of X-radiation. The blackening caused by a given dose of X-rays is also dependent on the hardness; a film is blackened more intensely by soft X-rays than by the same dose of hard rays. Since the secondary rays which occur in fluoroscopy are always soft the photographic method is very sensitive in this case.

For our purpose it was particularly important to measure the dose of rays on the most exposed parts of the body of the examiner, namely the hands. Several strips of film in light-proof wrappings were fastened to a pair of thin cotton gloves, and the blackening of this film was determined after 200 to 300 fluoroscope examinations. In different series of tests and with different doctors this was found to amount to an average of 0.02 to 0.03 r [2]). The

[1]) See J. G. A. van Weel, Philips techn. Rev. 1, 339, 1936.

[2]) The object irradiated has received the unit of dosage of X-radiation, 1 r, when a quantity of energy of 100 ergs would have been absorbed by 1 cc of water situated in the position of the object irradiated.

tips of the fingers were found to be the most exposed. From this point toward the hand the exposure decreased.

We may conclude from these results that the tuberculosis examination by the method used is not dangerous for the examining doctor. The daily dose with 60 examinations would, according to the above, amount the 0.006 r, while 0.02 r per day is given as the permissible dose [3]). This tolerance dose moreover may be considered a minimum value; cases are known in which ten times this dose was tolerated for years without harm.

By means of the method described above, which was worked out by Bouwers and van der Tuuk in this laboratory [4]), after the investigation on the doctors, it was also investigated whether there were persons in certain work-shops of the Philips factories who were exposed to too strong X-radiation during their work. Several remarkable "leaks" were actually found.

In the case of an inspector of X-ray tubes an intense blackening of the photographic film used for the test was obtained in spite of the fact that the tube to be inspected was screened by thick lead plates. The source was found to be another tube which was set up in the same room in such a way that, although the man who was using it was protected, the inspector mentioned previously was exposed to scattered rays. This condition was adequately remedied by means of a lead screen.

A second case was found in a workshop in which condensers were inspected by means of X-ray fluoroscopy. The condenser is placed on a small table and then raised by means of a pedal to a position in front of the window of the X-ray tube, which is working continuously. It was found that during the placing and removing of the condensers the hands were too strongly irradiated. This was remedied by causing the tube to be switched on and off by means of the action of the pedal. This also served to spare the tube.

From these cases it may be seen that a regular check on the dose of rays received daily is to the advantage of the employees of factories and laboratories where X-rays are used.

The observation of small objects in fluoroscopy

In order to reach a correct conclusion about the reliability of X-ray fluoroscopy as a means of detecting tuberculosis it is necessary to be able to measure the properties of the fluoroscope image on an objective basis. Many differences of opinion which exist in the literature on the utility of fluoroscopy for X-ray examination may certainly be ascribed partly to the fact that one investigator can distinguish much more than another at the brightnesses which prevail in fluoroscopy of the lungs. This in turn may be ascribed to differences in adaptation of the vision at low intensities and of the size of the pupil. It may also be ascribed partly to the apparatus used. For an objective judgement of the quality of the fluoroscope image a method has been developed by Burger and van Dijk [5]) which we shall now discuss. Since the tuberculosis examination in the Philips factories formed the stimulus for this investigation, especial efforts were made to imitate the conditions which prevail in the fluoroscopy of the organs of the chest.

An attempt was made to construct a body by means of nine "Philite" plates 0.8 × 20 × 20 cm which corresponded, not only as to absorption but also as to secondary X-radiation, as far as possible with the human thorax. Contrasting objects also made of "Philite" were then glued to one of the plates. These objects differed in size, shape and thickness (and therefore in contrast) and the conditions were studied under which the objects could be recognized on the X-ray screen. The arrangement is shown in *fig. 1*.

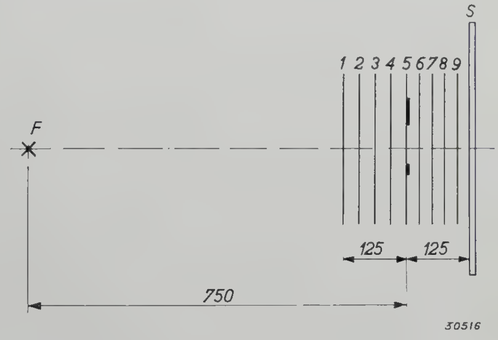

Fig. 1. Arrangement corresponding to the human thorax with respect to absorption and scattering of X-rays. *1-4* and *6-9:* "Philite" plates, *5:* plate with test objects, *S* screen, *F* focus of the X-ray tube. The dimensions are given in mm.

As an example of the results obtained with this arrangement, in *fig. 2* the length which the side of a square of "Philite" must have in order to be just visible is plotted as a function of its thick-

[3]) A. Mutscheller, Amer. J. Röntgenol. **13**, 65, 1925.

[4]) A. Bouwers and J. H. van der Tuuk, Fortschr.Röntgenstr. **41**, 767, 1930: see also C. H. J. Küthe, T. soc. Geneesk., June 1936.

[5]) B. van Dijk, Over de grondslagen en voorwaarden van optimale röntgendoorlichting (The basis of and condition for optimum X-ray fluoroscopy). Diss. Utrecht 1936. G. C. E. Burger and B. van Dijk, Fortschr. Röntgenstr. **54**, 492, 1936; **55**, 464, 1937; **58**, 382, 1938.

ness, *i.e.* as a function of the contrast caused by the square. It is found that under the circumstances given here (voltage on the X-ray tube 54 kilovolts maximum, current 3.5 mA) the object must have a thickness of at least 1.5 mm to be observable. With increasing thickness smaller objects can be observed; the smallest observable test object has a side of about 2 mm.

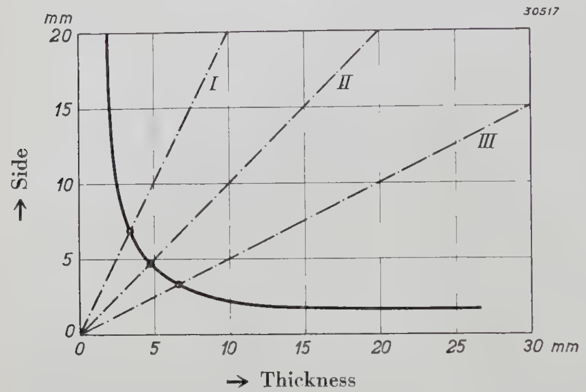

Fig. 2. Side of the smallest visible object as a function of its thickness, with an X-ray tube with a direct voltage of 54 kilovolts maximum and a current of 3.5 mA. On lines *I*, *II* and *III* the ratio of thickness to side is 2. 1 and 0.5 respectively.

The tests were made with contrasting objects of very different kinds: letters cut out of "Philite"; spherical objects and finally round holes in a "Philite" plate, since the latter could most easily be made with great accuracy and in great variety.

By means of such observations it was determined that a sphere with a diameter d is just as easily visible as a cube with the edge 0.8 d; the same relation exists within the limits of accuracy of the observation between a cylindrical hole and a square object with a height equal to the depth of the hole.

On the basis of this result it was permissible to carry out the observations exclusively with the help of round holes in a "Philite" plate, which meant considerable simplification. As a further simplification it was found possible to combine the "Philite" plates which imitate the absorption and secondary radiation of the thorax to two blocks 3.5 cm thick in front of and behind the test object. In an extension of the tests already described, in which the dependence of the visibility of square objects on their thickness was investigated (fig. 2), the dependence of this visibility on the current was studied. This could be done for the whole curve by determining for each value of the current how the dimensions of the smallest visible object vary as a function of its thickness. This variation, however, proved to be sufficiently clearly characterized by three points of each curve which correspond to definite geometrical shapes of the object.

In fig. 2 there are besides the curve three lines *I*, *II*, *III*. The points which lie on line *I* indicate objects with a thickness equal to twice the side, thus columnar objects; the objects on line *II* are cubical (thickness equal to side); the objects on line *III* are in the form of plates (thickness one half of the side).

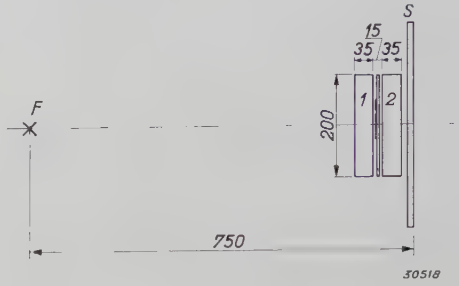

Fig. 3. Simplified arrangement for studying the visiblity of the X-ray image. *1* and *2* "Philite" blocks, *S* screen, *F* focus of the X-ray tube (dimensions in mm).

In different "Philite" plates 1 to 6 mm in thickness a large number of holes were bored whose visibility in the fluoroscope picture corresponded with those of square objects of the three abovementioned types:

I. Columns 1 : 1 : 2,
II. Cubes 1 : 1 1 : 1,
III. Plates 2 : 2 : 1.

The visibility of these objets was now studied as a function of the current. The results are shown in *fig. 4* in which the thickness of the smallest visible object of types *I*, *II* and *III* is plotted as a function of the current.

Using these and other results, an attempt was made to gain an idea of the influence exerted by

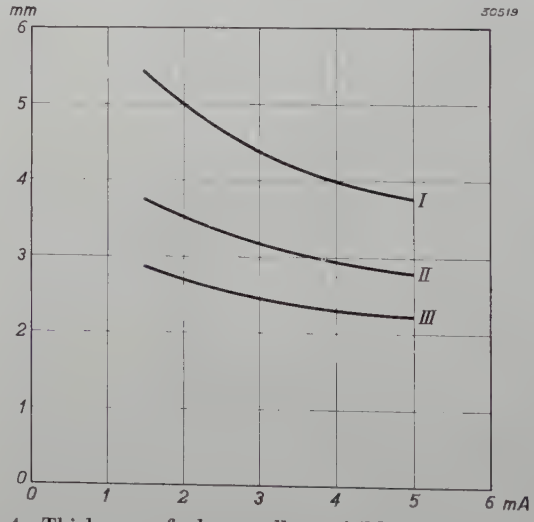

Fig. 4. Thickness of the smallest visible object made of "Philite" as a function of the current.
I: columnar object (1 : 1 : 2);
II: cubical object (1 : 1 : 1);
III: plate-shaped object (2 : 2 : 1).

different factors on the fluoroscope examination. The factors were:

1) Adaptation and disadaptation

The test persons were first adapted to a constant brightness and the progress of darkness adaptation was then studied. With the different test persons the time necessary for adaptation to darkness varied between 16 and 24 minutes. (The adaptation was considered complete when a continued stay of 6 to 8 minutes in the dark produced no increase in sensitivity to contrast).

2) The brightness of the fluoroscope image

The brightness of the fluoroscope image can be increased within certain limits by:

a) increasing the current;

b) raising the voltage;

c) increasing the light yield of the screen.

a) In tests on the influence of the current strength on the visibility of the fluoroscope image it was found that the current must be at least 2 mA in order to obtain a sufficiently visible image at a voltage of 54 kilovolts. If the quality of the image is considered to be inversely proportional to the size of a cubical object which is just visible, it is found that from 1 to 2 mA the quality increases by 50 per cent, from 2 to 3 mA by 14 per cent, from 3 to 4 mA by 9 per cent, from 4 to 5 mA and from 5 to 6 mA by 6 per cent. The quality of the image thus improves steadily with increasing current, but the improvement is not proportional.

If the dose of radiation received by the patient is measured under these various circumstances, it is found that, as far as danger to the patient is concerned, the permissible limit when the exposure is repeated weekly for several years is already reached at a current of 3 to 4 mA. In the case of a single exposure or repeated exposures at longer intervals a higher current is of course permissible.

b) In the case of an increase in brightness by increasing the voltage, the results, which varied considerably for different test persons, were less satisfactory than with the same increase in brightness by increasing the current. Upon an increase in voltage the ratios of brightnesses are usually decreased in the fluoroscope image just as in an X-ray photograph, so that the visibility is unfavourably affected. Nevertheless considerable improvement of the image can be obtained by increasing the voltage, since the brightness itself increases very sharply with increasing voltage.

c) As to the yield of light of the screen: the screen which has the greatest brightness with a given X-radiation gives the best results at the usual current and voltage.

3) The angle of vision in the observation of an object in the fluoroscope image

In general it may be expected that a small object which causes a certain contrast will be more easily recognizable the greater the angle of vision at which it is observed. For this reason the distance from which the screen is observed was kept as small as possible in connection with the accommodation of the eye, namely 16 cm.

Attempts were made to increase the angle of vision still more by examining the image with a magnifying glass or moving the object in the direction of the focus. In both cases the result was that with sufficient contrast in the fluoroscope image an improvement could be attained; with low contrast, however, the result was a decrease in the visibility. The cause of this decrease lies in a decrease in sharpness. The transition between bright and dark becomes less sharp with increasing enlargement, and therfore, in the case of low contrasts, less easily observable.

The influence of the sharpness of the image on the visibility was also investigated separately by comparing the images obtained with foci of different sizes. It was found that an X-ray tube with a focus of 1.4 mm gives about 25 per cent better pictures than a tube with a focus of 3.8 mm.

THE TESTING OF ELECTRIC FUSES WITH THE CATHODE RAY OSCILLOGRAPH

by J. A. M. van LIEMPT and J. A. de VRIEND.

The testing of electric fuses consists of determining their melting time as a function of the short circuit current. This measurement can be carried out very easily with the help of a cathode ray oscillograph. The measuring arrangement for this purpose is described. Melting time and short circuit current can be read off from a single oscillogram.

The melting time of electric fuses

It is important to know the time necessary for the melting through of fuses upon the occurrence of a short circuit. This time must be short enough to prevent damage to the apparatus or in the lines in series with the fuse before the fuse has melted. This is particularly so in the case of branches of a network which is protected by a main fuse when each branch contains an auxiliary fuse. The auxiliary fuse then serves to protect the main fuse, so that upon short circuit occurring in one branch of the network the other branches remain undisturbed. An example of this is the separate protection of certain pieces of apparatus, such as electric lamps, in order to prevent the melting of the main household fuse.

It is clear that the melting time t_s of a fuse will depend upon the short circuit current I_k. If t_s is sufficiently short to permit one to neglect the dissipation of the heat developed — this condition is satisfied when I_k is several times the limiting current, *i.e.* the maximum current which the fuses can carry for unlimited time — then the formula derived by G. J. Meyer [1]) holds for fuses which are initially at room temperature:

$$t_s = C\left(\frac{q}{I_k}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In this formula q is the diameter of the fuse wire and C the so-called absolute inertia constant which is characteristic of the material of the wire. By means of this formula the dimensions of a fuse for a given purpose may be determined. *Table I* gives the value of the constant C for a number of materials, which must be known for the determination.

If it is desired to test the usefulness of the formula for fuses of a given type, or to determine the constant C for a given material, t_s, I_k and q must be measured. For a given type of fuse q is constant. The problem is then the determination of corresponding values of I_k and t_s at which the product $I_k^2 t_s$ must theoretically be constant. $I_k^2 t_s$ is called the relative inertia constant. For ordinary household fuses of 15 and 6 A it has a value of about 200 and 40 A^2 sec. respectively. With a short circuit current of 50 A, for instance, the melting of the 15 A fuse therefore takes place within about 1/10 sec, the melting of the 6 A fuse in about 1/50 sec.

Absolute inertia constant C for several materials.

Material	10^{-6} C (A^2 sec/cm^4)
Copper	1000
Silver	720
Platinum	235
Monel	150
Constantan	135
Kruppin	80
Tin	45
Lead	40

Particularly in the case of thin fuses and (or) heavy currents the melting times may thus be very short. Since the measuring instrument to be used must have a sufficiently small inertia, the cathode ray oscillograph is particularly suitable. We shall give a brief description of the measurements [2]).

Measuring arrangement

By recording the current I at the moment of melting of the fuse as a function of the time t with the aid of the cathode ray oscillograph, I_k and t_s can be determined from the same oscillogram.

The diagram of the circuit of the measuring arrangement is given in *fig. 1*. The auxiliary or main fuse to be tested is introduced at Z. The short circuit current through the fuse causes a drop in voltage over the resistance R_1. This voltage is applied to the plates for vertical deflection of the cathode ray (terminals 5 and 7 of the Philips oscillograph GM 3 152; the amplifier of the oscillo-

[1]) G. J. Meyer, Zur Theorie der Abschmelzsicherungen, Verlag R. Oldenburg, München u. Berlin 1906, p. 36, and further: Elektrische Kraftbetriebe und Bahnen, 1911, Heft 7.

[2]) For a more detailed treatment see J. A. M. van Liempt and J. A. de Vriend, Z. Physik **93**. 100, 1934: **98**, 133, 1935. A theoretical calculation of the limiting current is given in: J. A. M. van Liempt, Z. Physik **86**, 387, 1933.

graph is disconnected). The short circuit current is supplied by a source of direct current introduced at E, and can be adjusted by means of the variable resistance R_2. The switching on of the short circuit current takes place by means of the relay r_3 supplied from the light mains. The resistances R_1 and R_2 are wound to be free of induction, in order to load the fuse immediately with the full current.

In order to make the current visible as a function of the time on the fluorescent screen O of the cathode ray tube, the light spot must be given a horizontal deflection proportional to the time. For this purpose the plates for horizontal deflection (terminals *1* and *2* of type GM 3 152; the time base of the oscillograph itself is of course disconnected) are connected to a condenser which in the equilibrium state is charged by the rectifier G connected to the mains. When the charging circuit is interrupted by the setting in action of the relay r_1, the condenser is discharged at a constant speed over the diode D, and the voltage between the deflection plates *1* and *2* falls proportionally with the time. By regulation of the heating current of the diode (resistance R_4) the rate of discharge and at the same time the time scale of the oscillogram can be varied. By means of the potentiometer P an adjustable positive bias is given to plate *1* with respect to plate *2*. The initial deflection of the light spot so obtained makes the full width of the screen available for the measurement.

A camera is placed in front of the screen of the oscillograph. The release of the shutter is coupled with the push-button S by means of a simple synchronizer such as is used by photographers for making flashlight photographs. The measurement is made by pressing this button. The low current relay r_2 is hereby put in connection at the same time that the shutter of the camera is opened; this relay in turn switches in the relays r_1 and r_3. The relays are so adjusted that r_1 begins to work somewhat sooner than r_3. Thus immediately after the light spot on the screen has begun its horizontal motion the short circuit current begins to flow through the fuse and the current-time diagram is traced on the screen. The shutter of the camera may be set at $^1/_2$ sec. for example.

In order to calibrate the scale of the current

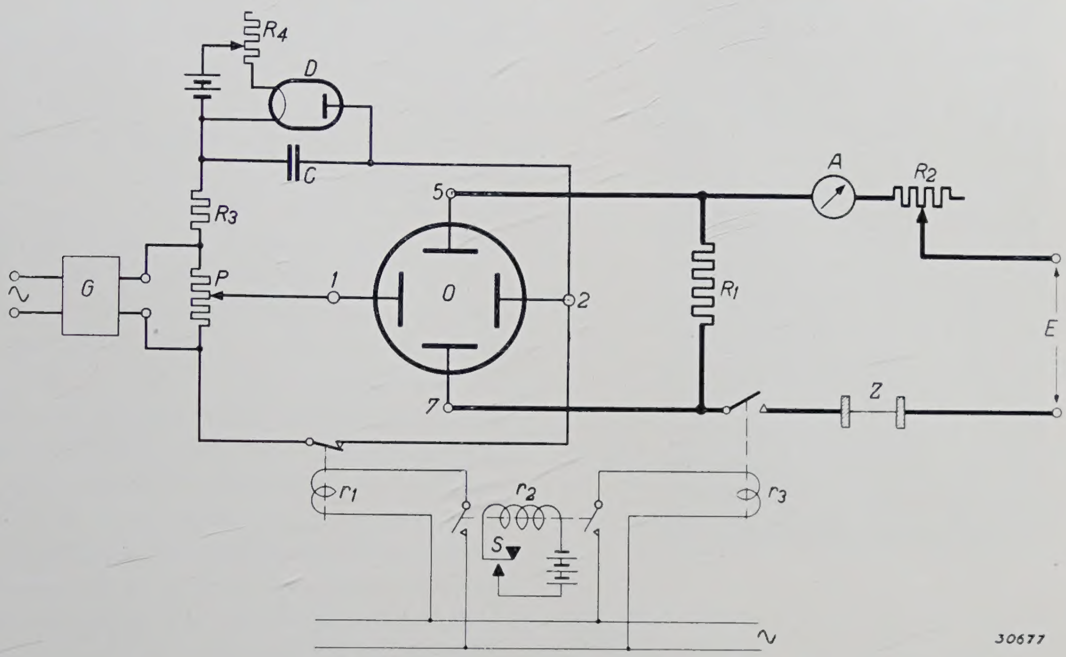

Fig. 1. Circuit for the measurement of the melting time of fuses as a function of the short circuit current. The part of the circuit drawn with heavy lines is for the purpose of obtaining a voltage proportional to the short circuit current on the plates for vertical deflection of the cathode ray oscillograph O. The source of short circuit current is introduced at E, and at Z the fuse to be tested. R_1 and R_2 are constant and adjustable resistance respectively, A ammeter, *5* and *7* terminals of the oscillograph GM 3 152. — A horizontal deflection of the light spot proportional to the time is brought about by the left-hand part of the circuit. G rectifier, C condenser, D diode with variable heating current (adjustable resistance R_4). The constant resistance R_3 serves to limit the charging current. P potentiometer, *1* and *2* terminals of the oscillograph — Upon pressing the button S the two heavy current relays r_1 and r_3 are brought into action *via* the low current relay r_2. These relays serve to switch on the time deflection and the short circuit current through the fuse.

another similar oscillogram is made on the plate in which the fuse is replaced by a strip of copper. The height of the line now traced on the screen corresponds to the current read off on the ammeter *A*. In order to calibrate the time scale a low auxiliary voltage from the mains is applied *via* a commutator to the terminals *5* and *7* of the oscillograph with the same adjustment of R_4. The period of the sine curve traced (1/50 sec with a mains frequency of 50 c/s) is a measure of the time.

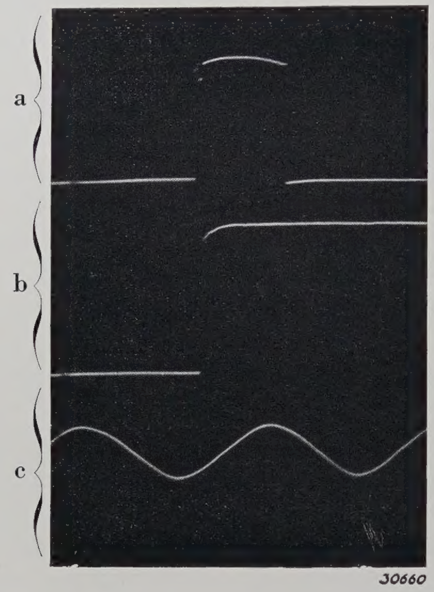

Fig. 2. a) Oscillogram showing the short circuit current as a function of the time, recorded with direct current.
b) Calibration of the current.
c) Calibration of the time.

In *fig. 2* an oscillogram recorded in this way is given of the melting through of a fuse together with the two corresponding oscillograms for the calibration.

Measurement with alternating current

The required heavy short circuit currents for the above-described measurements can be much more easily obtained with alternating current by means of a transformer than with direct current. The measurements are therefore usually carried out in practice with alternating current. In that case, however, formula (1) for direct current may not be applied directly. Instead of the relative inertia constant $I_k{}^2 t_s$ the following integral is used:

$$\int_0^{t_s} I^2\,dt$$

From the oscillogram which gives *I* as a function of *t* the value of the integral can be found by means of a simple formula, or it may for instance be determined directly with the help of a planimeter. In two cases the working out of the oscillogram is still simpler, namely:

a) when the melting time is large with respect to the period of the alternating current; formula (1) can then again be applied, provided that the effective value of the alternating current is taken for I_k.
b) when the melting time is so short that the alternating voltage may be considered constant within this time; this can practically only be the case when the moment of switching on, which is not directly under control, lies in the neighbourhood of a top of the sine curve (the peak value of the alternating current must then be used for I_k).

The calibration is simplified somewhat in the measurement with alternating current, due to the fact that for the calibration of the time no separate oscillogram is necessary, but the time scale can be read off immediately from the oscillogram for the calibration of the current.